Traffic Safety

Vol. 5 No. 4
December 1961

A NATIONAL SAFETY COUNCIL PUBLICATION

EDITOR

Murray Blumenthal, Ph.D.
Director, Research Division
National Safety Council

EDITORIAL BOARD

ASSOCIATE EDITORS

Norman Damon
Automotive Safety Foundation

E. H. Holmes
Bureau of Public Roads

TECHNICAL EDITORS

Earl Allgaier
American Automobile Assn.

J. Stannard Baker
Northwestern University Traffic Institute

David Baldwin
Institute of Traffic Engineers

Leon Brody, Ph.D.
Center for Safety Education
New York University

Clinton W. Dreyer
East Bay Chapter
National Safety Council

Bernard H. Fox, Ph.D.
Cleveland Psychiatric Institute

Merwyn A. Kraft
Flight Safety Foundation

Ross A. McFarland, Ph.D.
Harvard School of Public Health

Gordon H. Sheehe
Michigan State University

Fletcher D. Woodward, M.D.
Charlottesville, Virginia

The RESEARCH REVIEW is a quarterly supplement published by TRAFFIC SAFETY for the reporting of research that relates to traffic safety.

The opinions expressed and conclusions drawn are entirely those of the various authors of these papers. TRAFFIC SAFETY and the National Safety Council accept no responsibility for them, and publication should not be deemed as either endorsement or approval of the ideas expressed or devices described.

Manuscripts appropriate for publication should be submitted to the Research Division of the National Safety Council, 425 North Michigan Ave., Chicago 11. Manuscripts cannot be returned unless accompanied by a self-addressed, stamped envelope. Manuscripts should be typed, double-spaced in triplicate, and accompanied by an abstract of 200 words or less and all original art work. Any other information regarding research in progress or contemplated research can be submitted in any form that outlines the full particulars, i.e., investigator, problem, hypotheses, methodology, theoretical framework, etc.

RESEARCH REVIEW

2 The Reduction of Accidents in a Transport Company by the Determination of the Accident Liability of Individual Drivers—*Lynette Shaw and Herbert S. Sichel*

Evidence concerning "accident proneness" is gathered at a South Africa Transport Corporation by following the record of individual drivers on graphs recording the logarithm of the time interval between accidents.

13 A call for news of current traffic safety research for listing in the March issue of the *Research Review*

14 Case Studies of Traffic Accidents—*J. Stannard Baker*

An abstract of a pioneering attempt to employ an interdisciplinary team in the intensive study of motor vehicle accidents—and 1961 winner of the Metropolitan Life Award for Research in Accident Prevention.

18 Roadside Design for Safety—*Kenneth A. Stonex*

An application to the highway of a fundamental principal of safety engineering: "anticipate every type of accident which may occur because of machine failure or human failure and then establish safeguards to minimize the hazard or injury which may result when such a failure occurs."

31 The Auto Trainer as a Measure of Driving Performance—*Virtus W. Suhr and A. R. Lauer*

A summary of three experiments studying the auto training device, the effects of additional practice, and the intercorrelation of ratings given by instructors, supervisors, driver license examiners and test scores.

Readers of the *Research Review* are invited to submit letters to the editor commenting on articles appearing in this journal. When it is appropriate, copies of such letters will be forwarded to authors for reply. The original letter and the reply will then be published in the issue following.

Stock No. 329.97-19

Copyright 1961 by the National Safety Council, Printed in U.S.A.

The Reduction of Accidents in a Transport Company by the Determination of the Accident Liability of Individual Drivers

by Lynette Shaw and Herbert S. Sichel

Mrs. Lynette Shaw, as manager of Industrial Psychological Services, Johannesburg, South Africa, has guided the development and the researches of this organization for the past eight years. She has pioneered the use of professional driver aptitude tests for both Europeans and Africans in South Africa.

Mrs. Shaw is a graduate of the University of the Witwatersrand, where she gained a B.Sc. degree in mathematics. Her interests span an area encompassing research into the question of "accident proneness," the problem of the criterion in accident studies, the development and validation of tests for predicting accident liability, and the personality patterns of accident offenders.

In view of the importance of such problems within the emergent African states, Mrs. Shaw has made a specialized study of the African driver.

Herbert S. Sichel is director of the Operational Research Bureau, Johannesburg, South Africa. He received his B.Sc. degree in 1938 from the University of Pretoria and attained his M.Sc. degree in 1950 and his D.Sc. in 1953 at the University of the Witwatersrand, Johannesburg.

He is especially interested in the development of the theory of mathematical statistics and its application to practical problems. He has published over 40 papers on theoretical and practical topics connected with statistical and operational research.

Dr. Sichel was elected a member of the International Statistical Institute in 1957 and in 1958 he was made a fellow of the American Statistical Association. He is also a fellow of the Royal Statistical Society, past president of the South African Statistical Association, member of the Psychometric Society and member of the South African Institute of Mining and Metallurgy.

SUMMARY

This paper outlines the development of a research project on accident occurrence and accident liability carried out in a South African transport company employing African bus drivers.

The project has involved the study of the company's corporate accident statistics and also a detailed statistical analysis of the records of 898 African bus drivers.

As a result of the study of the corporate accident statistics, methods were evolved for recording accident occurrence on control charts which were sensitive enough to highlight any significant trends and practical enough to form a basis for the managerial policy on accident control.

The study of the individual records of this large body of professional drivers, equalized as to physical fitness, training, experience and driving risks, revealed that the accident potential of each individual driver was different and was also so consistent as to represent a function innate in that individual.

As a result of the study of these individual records, a system was devised for establishing control charts for each of the drivers and for classifying them as accident risks. By these means it was possible to detect existing and potential accident offenders. The gradual elimination of these offenders and their replacement by men of a better calibre has resulted in a decrease of 38 per cent in the company's accident rate over the last eight years. (The new drivers were selected by means of psychological tests which will be described in a later paper.)

The writers submit that this investigation provides confirmation of the concept that certain people are inherently bad road accident risks, and illustrates the substantial reduction in accidents that can be brought about by not allowing such people to drive. They feel that these findings accentuate the need for systematic research on the human factors in accidents and for effective action to be taken as a result of this research.

INTRODUCTION

An extensive psychological and statistical research project on road accidents has been in progress over the last eight years in a transport company in South Africa.

The research project has been an essentially practical one, the aim being to reduce the company's accident rate.

The project is too comprehensive to be covered in one paper and three papers are being prepared, one general, one statistical and one psychological. This is the general paper. It covers the development of techniques for recording accident statistics and for evaluating accident liability in individual drivers. It also covers the practical application of these techniques in the transport company and the results achieved thereby. The second paper will deal with the statistical techniques used (many of them new) and is being prepared for publication in a statistical journal by one of the present writers, H. S. Sichel. The third

paper will deal with the psychological techniques evolved for the selection of new driver intake (particularly the use of projective techniques for predicting accident liability) and with follow-up studies of this selection.

The project has been carried out by Industrial Psychological Services and the Operational Research Bureau, who are respectively the psychological and statistical consultants to the transport company. The investigation covers the records of 898 African bus drivers with exposure periods of up to 10 years.

THE GENERAL BACKGROUND OF THE RESEARCH PROJECT ON ROAD ACCIDENTS:

The company in which the investigation was carried out, Public Utility Transport Corp. (PUTCO), is a company supplying most of the bus transport for the non-white communities of the South African cities of Johannesburg and Pretoria.

The drivers are all non-whites—mainly Bantu, with a small admixture of Coloreds and Indians.* These drivers operate diesel-powered buses, most of which are large 85-passenger-carrying single-decker vehicles. Most of the driving is done in heavy city traffic and between them the drivers travel 11 million miles a year.

The cities of Johannesburg and Pretoria have the unenviable record of having one of the highest accident rates in the Western World (the death rate per vehicle registered in Johannesburg is reported as being four times that of New York). A variety of causes, ranging from dense traffic in narrow streets to a polyglot population with a fast pace of living, all contribute to this high accident rate. When one adds to this the conditions prevailing in the rapidly-expanding and often overpopulated Bantu townships on the outskirts of these cities, it will be appreciated that a company operating Bantu transport is bound to have its bus fleet involved in a considerable number of accidents.

What may be termed an operational headache is, however, a statistician's opportunity and the records of a company functioning under conditions such as these provide ideal material for an investigation on accident occurrence.

The company has been operating since 1945 but this particular investigation has been limited to the years of 1951 to 1960 inclusive. It covers the analysis of the accident records of 898 bus drivers employed by PUTCO during this time.

These records are kept in very great detail. Each driver has an individual accident file containing comprehensive forms which are filled in for each accident in which he is involved. These forms give, inter alia, the driver's account of the accident, statements taken from witnesses, the findings of the official investigating the accident and details of causation. They also contain an assessment of the seriousness of the accident and the degree of culpability which can be attributed to the driver. In addition, records are kept of any unusual time off driving, such as annual leave, sick leave, absenteeism, etc., so that it is possible to calculate actual driving exposure.

*The South African Information Service defines Bantu as the generic term for Negro tribes, Colored as persons with a mixture of white and non-white blood lines, and Indians as descendants of immigrants from India.

In addition, this exposure is standardized. Although traffic conditions differ in the various divisions of the company, it is possible to assess the effects of these differences. Within each division the conditions are the same for each driver. The buses are the same and each man drives an eight-hour shift. The shifts are changed from time to time so that over a period each driver is exposed to the same traffic risks.

All the drivers are trained to a high degree of driving proficiency and regular inspections are made to insure that this is maintained.

The age of each driver is known and information is available as to whether he had driving experience before joining the company. They are all literate and the minimum educational level is Standard 5 (post elementary school).

All the drivers are given regular medical and optical examinations and are required to meet high standards of physical fitness, vision and hearing.

Every incident, however trivial, in which the company's vehicles are concerned is regarded as an "accident" and is recorded on the file of the driver concerned. Over the 10 years covered by the investigation, the 898 drivers were involved in 7,452 "accidents."

Because of the difficulty of finding good bus driver material amongst the African population, the company has often been unable to discharge unsatisfactory drivers. This has provided unusual evidence of repeated accident occurrence over periods of long exposure.

With this wealth of material it was possible to carry out a very comprehensive investigation on road accident occurrence, the general outline of which is given here.

THE RESEARCH PROJECT

The investigation followed two main lines:

(1) The analysis of the total accident statistics of the company;

(2) The analysis of the accident records of each individual driver.

The Analysis of the Accident Statistics:

The purpose of this investigation was to find a method of recording and presenting the company's accident statistics in a form which would provide easily-understood visual evidence of any significant trends in the accident position.

There are four divisions of the company, three in Johannesburg (Wynberg, Kliptown and Martindale) and one in Pretoria. Within each division the operating conditions are very homogeneous; but between divisions there is a definite difference. For better managerial control it was decided, therefore, not only to draw trend graphs showing the accident rate of the company as a whole, but also to devise control charts for each separate division. The statistical unit which was chosen as being the most meaningful was the number of operational accidents in relation to the number of miles driven.

In order to determine the number of operational traffic accidents, the following practices were adopted: every reported occurrence in which the company's buses were involved in collision with any object whatever was regarded as an "accident"—whether any damage resulted from the occurrence or not, whether the company's vehicle was

moving or stationary, and whether the company's driver was regarded as being blameworthy or completely blameless.

It was appreciated that in compiling the statistics in this way, certain accidents were likely to be included where the occurrence was completely unavoidable and where it might be unfair to debit the company with the accident. After due investigation it was found, however, that the number of such occurrences in relation to the total number was small and the distribution was so random, that their inclusion would not fundamentally affect the over-all pattern, certainly not enough to compensate for the delay involved in waiting for evidence on which to decide whether an occurrence should be included or not.

In order however to limit the scope to "operational" accidents, the following easily assessed occurrences were omitted:

(a) "Platform" accidents involving unauthorized boarding and alighting of passengers.

(b) Accidents unrelated to driving, such as damage to the company buses caused by falling debris, weather, riots, etc.

(c) Depot occurrences, such as damage caused to the buses in the depots during night parking.

(d) Accidents incurred by non bus drivers, such as workshop personnel testing buses.

Working on this basis and using a time unit of 28 days, accident rates were then worked out in terms of the number of accidents per 10,000 miles driven per 28 day unit. These rates were calculated for each of the four divisions and for the company as a whole.

A system of control charts was then devised for each division, the limits of the control chart were set as follows:

It was established from theoretical consideration and also from actual observations that the number of accidents per 10,000 miles driven was distributed according to the Poisson distribution law. Appropriate limits were therefore derived from the cumulative Poisson distribution using the average number of accidents in each division as an estimate for parameter λ. The probability levels could not be chosen exactly at .001, .025, .500, .975 and .999, as is usual practice in control chart work, because of the discrete nature of Poisson variables.

Consequently the limits were calculated for levels as near to the above as was possible for each individual division. Finally, by dividing these limits for number of accidents by the average mileage driven $\times 10^{-4}$ the required limits for the accident rates were obtained.

The practical application of this part of the investigation

The system of graphs and accident control charts has now been in functional use for a period of three years. Copies of the charts are distributed to top management and each division and are kept up to date from a central source. As they furnish an easily understandable picture of accident trends, they have proved extremely valuable and form the basis of the managerial policy on general accident control.

Several points of interest in connection with the system are worthy of mention here.

It has been found that the charts not only reflect general trends but are so sensitive that they reflect such factors as:

1. the competency of local management
2. the effects of changes in such management
3. the effects of special measures such as intensified accident prevention campaigns
4. the effects of local events such as civil disturbances.

The following examples illustrate these points:

In one division (Fig. 1) the accident rate suddenly dropped and remained outside the limits of the control chart for some time. This was at first attributed to the beneficial effects of appointing a new official but the unusually small amount of fluctuation between the points aroused suspicion and an investigation revealed that the drop was, in fact, due to the incorrect reporting of accident occurrence.

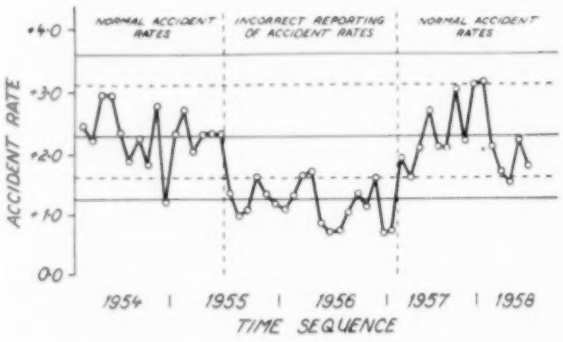

Fig. 1

Portion of a divisional control chart revealing the incorrect reporting of accident occurrence. (Note: In all cases the "accident rate" is the number of accidents per 10,000 miles driven.)

In another division, where the drivers were mostly older men with long service, a popular divisional superintendent who had been there for a long time, was replaced by another official. The accident rate immediately showed a significant increase and did not revert to normal for nearly a year. Fig. 2 gives portion of the divisional control chart showing the change in management followed by three successive points above the upper warning line and a highly significant run of seventeen points above the median line.

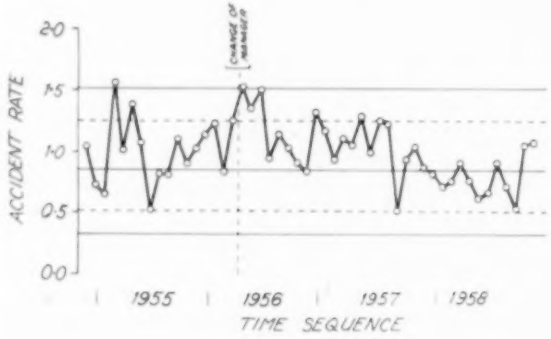

Fig. 2

Portion of a divisional control chart showing a significant increase in the accident rate due to the removal of a popular supervisor.

On several occasions the accident rate of the company has reflected general unrest caused by local disturbances. In 1957, when a rise in the bus fares resulted in a boycott of the company's buses, the feeling of general unrest

was reflected in the accident rate. Even after the boycott was over the accident rate did not revert to normal for several months. The same phenomenon was observed at the time of the Sharpeville disturbances in 1960 (Fig 3).

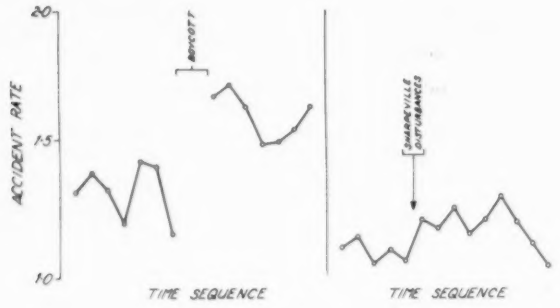

Fig. 3

Portion of the trend graphs of the company as a whole showing the effect of civil disturbances on the accident rate.

The control charts and trend graphs have provided concrete evidence of the fact that the accident rate throughout the company has fallen appreciably. In fact, as of June 1961, the charts of all four divisions have shown almost unbroken runs below the median line over the last 18 months. Fig. 4, which is a five-point moving trend graph of the accident rate of the company over the last ten years, clearly demonstrates this improvement. It shows a fall in the accident rate from 2.4 accidents per 10,000 miles driven in 1951, to 1.1 in 1961. This present rate means that the average performance of the company's drivers is one accident (which may, in fact, be a very minor incident) for every 9,000 miles of city driving.

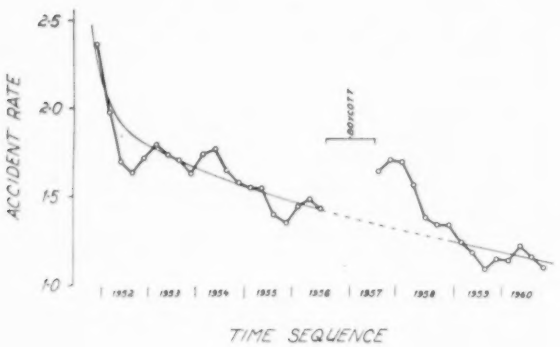

Fig. 4

Trend graphs of the accident rate of the company from 1951 to 1961.

The Analysis of the Accident Records of Each Individual Driver:

At an early stage in the research project it was decided to undertake a detailed study of the individual accident records of the company's drivers. The main objects of this study were:

1) To establish whether individual drivers did have individual accident patterns.

2) To establish a reliable method of classifying the company's drivers on the basis of their accident records.

3) To determine whether it was possible to predict a driver's future accident record on the basis of his past record.

4) To establish an accident criterion against which to measure the success of new driver selection methods.

5) To apply the findings of the investigation for the purpose of reducing the company's accident rate.

(Note: It is gratifying to note that as a result of this investigation all these objects have been achieved.)

Basically, the investigation boiled down to a practical research project on the much debated question of "accident proneness." The approach to the problem of accident proneness by means of the study of individual records was a somewhat unusual one. Previous studies on proneness have largely concerned themselves with the study of groups of drivers, and attempts have been made to establish whether predictions of future behavior could be made on this basis. These studies have yielded rather poor results. In the opinion of the present writers, this is largely because of the "blanketing" effect of any group technique, where predictions for the behavior of any one individual are made on the basis of the pattern of a group of which he happens to be a member.

The individual approach was therefore regarded as being more likely to yield good results. Another and more important consideration was, however, the fact that the research project was essentially a practical one and in practice it is the individual that counts, particularly in the operation of a transport company. In such a company the composite accident rate is the summation of the performance of its individual drivers, and managerial policy cannot hope to be effective unless it has a means of assessing each driver on his own particular merits.

For this reason the research project resolved itself into an attempt to establish a reliable method of evaluating accident liability in individual drivers.

The Research Project on Individual Drivers

The first objective of the study was to investigate such features as:

What was the important feature of a man's accidents —was it the frequency, or the severity, or the degree of blameworthiness, or the outcome in terms of property damage, injury or death? Was there any meaningful pattern in an individual's accidents or were they merely occurrences dictated by chance? What was the effect of experience or long exposure? Did the drivers improve over the years?

To achieve this study the individual records of all drivers employed by the company since 1951 were assembled and analyzed in detail.

The question of severity was considered first. Although some interesting trends were disclosed, in that several drivers appeared to have more than their fair share of "major" accidents (accidents where the costs exceeded £100), this approach did not yield any very helpful results.

This was not regarded as surprising, considering the fact that the outcome of an accident in terms of costs, or in terms of injuries or death, is often purely fortuitous.

The question of the blameworthiness of the driver was then considered. Every accident sustained by every driver over a period of five years was assessed by experienced officials of the company's accident bureau and was graded on a five point scale: 100 per cent to blame, 75 per cent, 50 per cent, 25 per cent and 0 per cent. It soon became apparent, however, that this approach, although laudably comprehensive, would not prove very practicable either. In over 50 per cent of the accidents, the accident bureau officials rated the company's drivers as entirely blameless. On the face of it, this appeared to be extremely improbable and further investigation confirmed this fact.

In the first place, it was found that often the only evidence available was the driver's own statement—a statement which naturally presented his case in the most favorable light. In the second place, the assessors, who happened to be the men most competent to do the assessment, happened also to be the officials who handled all the accident claims—with the result that they were in all probability conditioned into thinking with a definite bias in favor of the company's interests.

It appeared therefore that a rating system such as this, although intended for the objective allocation of driving blame, was in fact merely a reflection of such functions as the assessor's way of thinking, or the driver's ability to present a good case for himself. Subsequent attempts to arrive at a true assessment of blameworthiness were equally disappointing and, in the end, the whole approach of differentiating between one accident and another had to be condemned for statistical purposes as being too subjective, or too dependent on chance or on the reliability of the evidence available.

For day-to-day managerial purposes, however, a new system was devised whereby each accident was given a code number indicating that, on the basis of the evidence available the driver was:

1) apparently blameless
2) guilty of only very minor negligence
3) guilty of definite negligence
4) guilty of reckless and dangerous driving
5) guilty of driving under the influence of liquor

This coding was found to be very useful for disciplinary purposes.

It was therefore decided that though all relevant information concerning accidents was of interest and of administrative value, the only reliable unit for statistical purposes was the number or rather the frequency (meaning the pattern of the occurrence) of an individual's accidents and the research program was therefore directed towards an intensive study of this factor.

Fortunately it was later established that by limiting the investigation to this one aspect very little was being lost. It was later proved that the frequency of an individual's accidents is not only a reliable statistical measure, but also a highly significant one. Whatever the result of an accident and whatever the degree of the driver's blameworthiness, the fact that he is involved in a situation resulting in an accident is apparently very significant and the frequency with which he is involved is even more so.

There are certain occasions, however, when there is objective proof that a particular driver is completely blameless and his involvement is so fortuitous that it would be illogical to debit him with the accident.

For the purposes of this investigation (and bearing in mind the conditions under which the company's drivers operated), the following accidents were therefore excluded from the frequency calculations as being fully blameless:

1) an accident involving a bus which had been stationary for some time and which had been correctly parked in an authorized place.

2) damage due to riots or falling debris, etc.

3) platform accidents involving unauthorized boarding and alighting of passengers. (It was appreciated that in some cases the driver may not have been altogether blameless but the greater behavior of Bantu passengers in crowding the buses and jumping on and off when the vehicle is in motion is such that it is usually impossible for the driver to control their activities.)

4) very occasional occurrences, such as a case where a vehicle driven by a drunken third party had crashed, out of control, into one of the company's buses.

5) accidents due to the development of unavoidable mechanical defects on the buses.

As this procedure still contained a certain degree of subjective judgment, a statistical check was made to test the validity of the premise on which it was based. It was argued that if the reasoning was incorrect then the investigation would show up that certain drivers were getting away with more "fully blameless" accidents than others. This was not found to be the case and the distribution of these blameless accidents was found to be a Poisson one and therefore in all probability dictated purely by chance.

The investigation then turned to the question of what could be gained by studying the pattern of the occurrence of each individual driver's accidents. To do this it was necessary to have a schedule of accidents and a schedule of time-off driving in order to establish the actual exposure time between accidents. Because of certain untraceable minor factors such as on what day the weekly "day-off" occurred, it was decided that it would be impracticable to go into the question of time-off driving in too fine detail, and that any period of less than three days absence should be ignored. This system was later found in practice to be quite sufficiently sensitive.

Working on this basis, an accident build-up sheet was then drawn up for each driver. These sheets produced the following information:

a) The time intervals between successive accidents (the first time interval being the interval between the start of exposure to the first accident). These intervals, expressed in terms of actual driving time in days, were given the designation "t."

b) The logarithms of these time intervals.

c) The cumulative average of these time intervals.

Each driver's record was then transferred onto an individual control chart with the abscissa recording the number of each successive accident and the ordinate, the logarithms of the time intervals (t_m) between these accidents. The statistical theory on which the control charts are based is as follows:

If the accident liability of an individual driver is constant, in time it can be proved that the time intervals between successive accidents are distributed according to the negative exponential law.

If the averages of time intervals (t_m) are different for different drivers it follows that, due to the standard deviations being equal to the means, no fixed control grid can be applied. This difficulty may be overcome by using a logarithmic transformation of the time intervals. This has the great advantage of equalizing the standard deviations, thus making it possible to use one set of control limits for distinguishing between good and bad drivers. In Fig. 5 the histogram of 4864 logarithms of observed time intervals adjusted to zero median is superimposed on to the theoretical distribution law. The agreement between the observations and the theory is excellent and the objective Chi Square Test does not reject the hypothesis of exponential time interval distributions for individual drivers. It is therefore possible to derive the correct limits from the theoretical distribution, as indicated above the histogram of Fig. 5.

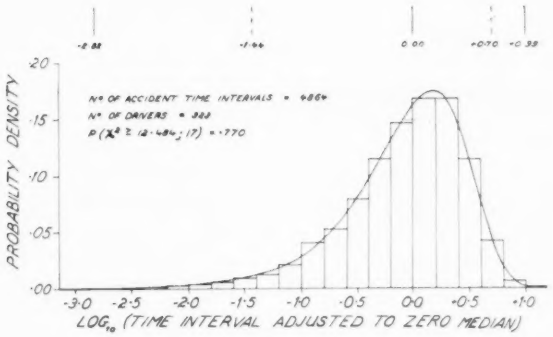

Fig. 5

Observed and theoretical frequency distribution of logarithms of time intervals between accidents with zero median as origin.

Specimens of these time-intervals control charts for individual drivers will be given later in the text. In reading them, the following features are of importance:

1) The significant factor is not the number of accidents (for this may be dependent on short or long total exposure); it is the time interval (t_m), i.e. the height of each point on the ordinate.

2) A good record (Fig. 6) is one where the points are mostly above the line indicating the median for that division.

3) A bad record (Fig. 7) is one where the points are mostly below the median line for that division.

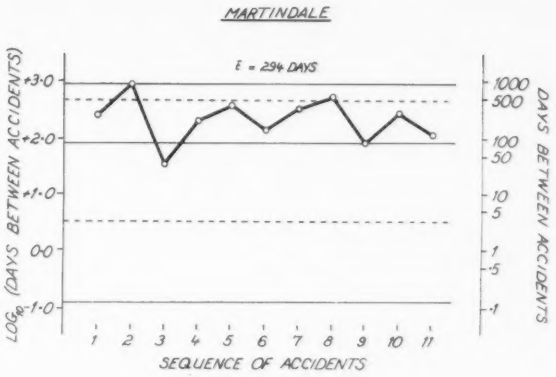

Fig. 6

The control chart of a driver with a good record and most of the points above the median line and only 11 accidents in nine years (an average of 20,000 miles of driving between accidents).

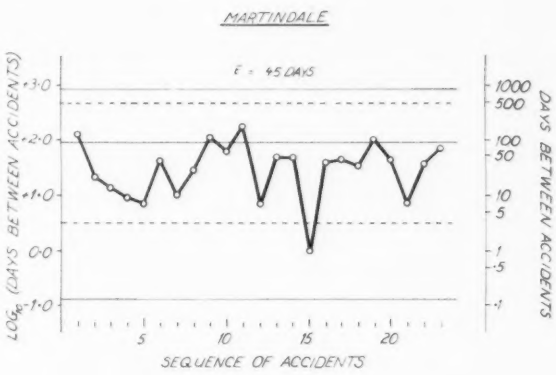

Fig. 7

A bad record with most of the points below the median line and 23 accidents in three years (an average of 3,000 miles of driving between accidents).

4) An upward trend indicates a lengthening of the time intervals, i.e. an improvement.

5) A downward trend indicates a shortening of the time intervals, i.e. a deterioration.

A study of the accident graphs and the build-up sheets of all the drivers produced the following valuable information:

a) In many of the drivers, particularly the relatively inexperienced ones, a definite learning period of up to six months was clearly discernible. During this learning period, a new driver usually had several accidents at relatively short intervals.

b) At the end of the learning period a pronounced improvement was noticeable, the time intervals became longer and each driver developed an individual accident "pattern." The cut-off of the learning period was so obvious that it was possible to exclude this period when evaluating his true accident liability. Fig. 8 shows a typical learning period followed by a stable accident pattern.

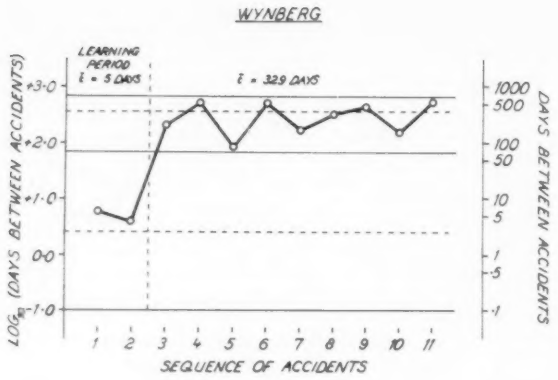

Fig. 8

A typical learning period followed by a stable and good accident pattern.

c) This pattern was remarkably consistent, so consistent, in fact, that it was apparent, even to the eye, that the time intervals (t_m) were not dictated by chance but that they played around a stable level. This level was different for each individual driver.

d) The graphs were so easy to read that it was possible, by eye alone, to mark off the learning period and make an estimate of that driver's individual level of accident liability. In practice, this rough estimate was usually a very close approximation to the actual mathematical mean (t_m) of the intervals calculated from his build-up sheet. Fig. 9 shows the control chart of an individual driver illustrating the stability of an accident pattern.

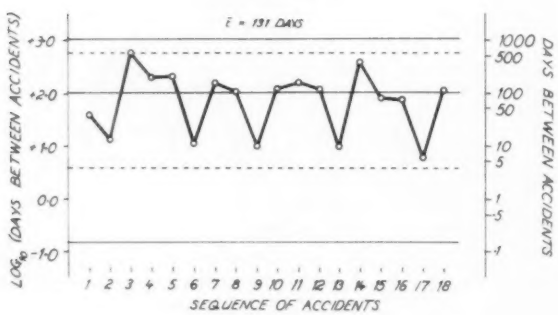

Fig. 9

The control chart of an "average" driver illustrating the stability of an accident pattern.

e) Significant learning periods were only found among the men who had turned out later to be good accident risks.

f) In the case of the bad risks, "accident-proneness" was definitely exhibited. These drivers had started with short time intervals between accidents and, even after the period when learning should have ceased, had continued to show no real improvement. Fig. 7 is a typical case of a bad record extending over three years with no real improvement. In many of these instances the driver had eventually been discharged but not before he had been involved in a number of accidents. Fig. 10 shows the record of a driver who, over a period of 10 years, had been involved in one major and 44 minor accidents. Disciplinary action was always followed by a period of improvement, but in each case this was only temporary. Towards the end of his career he was given a severe reprimand and told that he would be taken off driving if he did not reform. He then had fewer accidents which made him overconfident and he finally caused a major accident for which he was discharged.

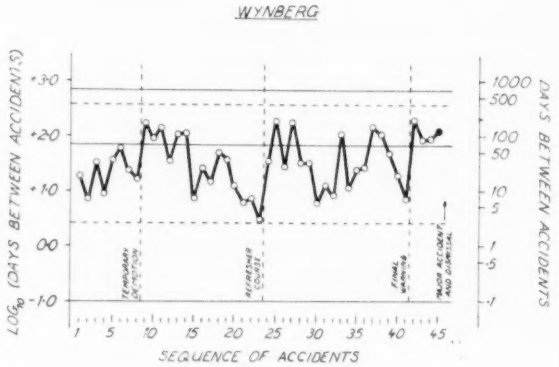

Fig. 10

A record with 45 accidents in 10 years showing the purely temporary effect of disciplinary action on a very unsatisfactory driver.

g) Only in an unexpectedly small number of cases was there evidence of gradual improvement over a period of years (Fig. 11).

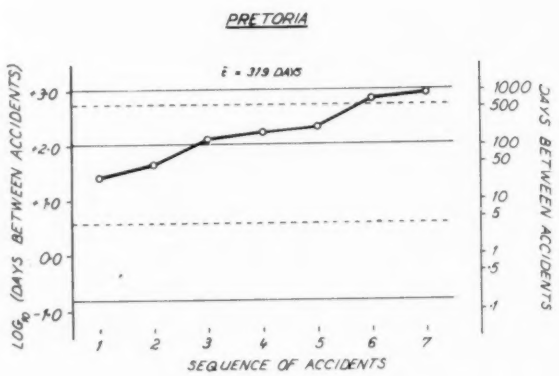

Fig. 11

Record of a driver showing steady improvement over a period of six years.

h) In the majority of the cases, once the initial quick learning period was over and the driver had attained his own individual level, he remained there and only very minor variations occurred in the pattern of his graph or in the cumulative average of the time interval between his accidents, as shown in his build-up sheet (see Fig. 8).

i) Where a significant variation did occur in the pattern, indicating marked deterioration, this could usually be correlated with some definite cause such as ill health, domestic or other worries or his taking to drink. Fig. 12 shows the deterioration in the record of a driver after his wife had run away (with his life's savings).

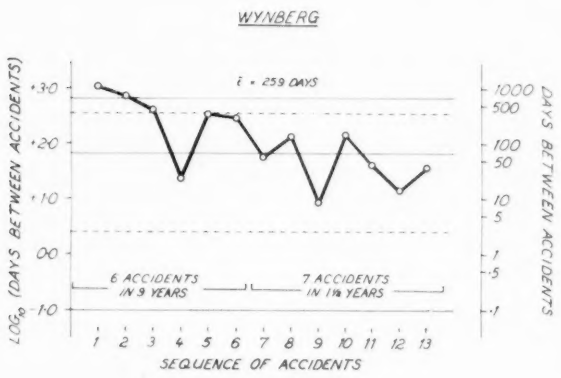

Fig. 12

The record of a good driver showing a significant deterioration caused by domestic worries.

j) A very interesting phenomenon was demonstrated in the control charts of men who had been transferred from one division to another and who had to adapt themselves to driving under different conditions. In each case the transfer was accompanied by a change in the level of the pattern of time intervals between accidents; but here again the individuality of each driver's specific accident potential was clearly demonstrated. In most cases the change in level was purely relative, e.g. a driver with a good t_m (average time interval) transferred from an easy division to a more difficult one would have shorter time intervals but the new level of his t_m on the control chart would still be above the level of the median t_m for the new division. In other cases, however, the control charts of transferred drivers would reveal either a significant improvement showing that this particular individual functioned better in this new division than in the old, or a significant deterioration showing that he was unable to cope with the new conditions. Fig. 13 shows the significant fall in the level of the time intervals between accidents of a driver transferred from the Pretoria Division, where traffic conditions are relatively easy and where his t_m was very satisfactory, to the Wynberg Division where, even by Wynberg standards, it was dangerously low.

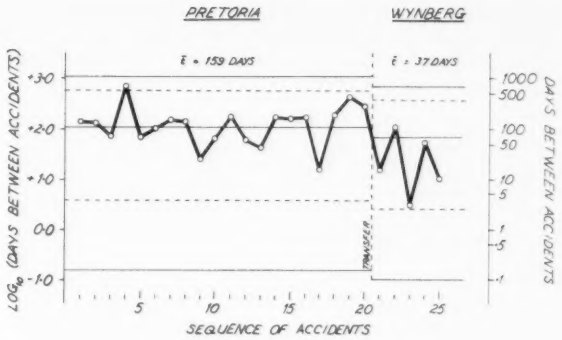

Fig. 13

Control chart showing the effect of an inter-divisional transfer on a driver unable to cope with more difficult traffic conditions.

k) Full 90 per cent of the drivers displayed accident patterns that were so consistent in themselves that, on the basis of a man's past history, it was possible to predict what his future record would be like (predictions which have been borne out in practice during the three years since the system was first inaugurated).

Of the remaining 10 per cent, most of the changes in accident pattern had occurred because of some definite explainable circumstances. There were, however, a small percentage of the drivers whose records showed no particular pattern and fluctuated in a manner that made predictions of future behavior very difficult. Later experiences proved, however, that the very fact that these people did fluctuate meant that they were not good risks. In many cases it was found that these men were drinkers.

l) Major or serious accidents were found to occur mostly in the records of the drivers with the short time intervals. Over a period of six years, during which time only 20 per cent of the drivers displayed patterns of short time intervals, 60 per cent of the serious accidents (accidents stemming from reckless and dangerous driving) were caused by drivers in this category.

m) The effects of age were clearly demonstrated by factors such as:

1) The greater incidence of bad records and unduly expensive learning-periods amongst the young drivers. (One young driver of 19 who had slipped in by falsifying his age had a learning period of two years).

2) Obvious deterioration among certain of the older drivers after the age of 50.

These factors were so evident that the company's regulations were altered; the age of admission for drivers was gradually raised from 21 to 26 and stricter checks were kept on the records of all the older men.

It was, however, found that there was an appreciable difference between the accident liability of individual drivers of the same age.

These observations were made on the study of the in-

dividual records of 898 drivers. They were later confirmed by an exhaustive statistical analysis of all the available data. (Details of this analysis will be given in the statistical paper by Sichel.)

The most significant aspect of the whole investigation was the proof it provided of the individuality of each driver's accident liability, and of the fact that this liability was so consistent that it was possible to predict what sort of an accident risk a man was likely to be in the future on the basis of his past behavior.

THE PRACTICAL APPLICATION OF THIS PART OF THE RESEARCH PROJECT

As one of the primary objects of the whole research project had been to find a sensitive and reliable method of assessing the accident liability of individual drivers, the success of the research study had important practical implications. It was possible now to maintain visual accident records of all the company's drivers and also to devise a method of grading them into various accident categories for the purpose of managerial control. Using the means and the range of the t_{ms} of the current drivers, it was possible to set separate standards for the traffic conditions prevailing in each division and a system was devised for classifying the drivers into five categories in such a way that the relative meaning of each category was the same for each division.

The following tables show the limits of the t_{ms} set for each division in order to obtain five accident categories:

Categories	Range of t_{ms} (Average number of days between accidents)			
	Wynberg	Pretoria	Martindale	Kliptown
A Excellent	200 & ov.	300 & ov.	250 & ov.	300 & ov.
B Good	125 - 199	175 - 299	150 - 249	175 - 299
C Satisfactory	75 - 124	125 - 174	100 - 149	125 - 174
D Poor	50 - 74	74 - 124	50 - 99	75 - 124
E Bad	0 - 49	0 - 74	0 - 49	0 - 74

It will be noticed that the spread of t_{ms} is narrowest in Wynberg where the traffic conditions are very difficult and widest in the Pretoria and Kliptown Divisions where operating conditions are much easier.

Having established a basis for a classification system, consideration was given to the most productive ways in which this could be used.

It was decided that a classification based purely on the cumulative average of the time intervals (t_{ms}) would be the most reliable criterion for such factors as follow-up studies on new driver selection.

For operational purposes, however, it was felt that a more flexible assessment was necessary, i.e. one that would be more sensitive to any current trends, such as an improvement warranting recognition or a sudden deterioration needing immediate attention. An assessment such as this, although somewhat subjective, would be more useful for practical purposes as it would give a picture of each man's liability at that particular moment.

It was decided therefore to develop an operational classification which could be based on a study of the trends, both of the build-up sheet and the control chart. If, for any reason, a man's accident level was changing significantly, notice would have to be taken of that fact, even if the t_m calculated over his whole exposure had not yet been sufficiently affected to bring him into a different statistical category.

On this basis, a new procedure was evolved for bringing out six-monthly accident ratings for each division of the company. These ratings were prepared in the form of:

1) schedules of all drivers in the various categories

2) a summary of the numbers and percentages in each category to indicate the improvement or deterioration in the general position since the last six-monthly rating

3) a detailed list of all drivers, giving their accident categories and also relevant comments about each one. Examples of these comments are given below:

Company No.	Name	Category	Comments
168	Peter Mashodi	A	Excellent. One of the best records in the division.
193	William Nkosi	B	Good, but not as good as he used to be. Now 52 years old. Watch.
2096	Moses Sibidi	C	Satisfactory.
2394	John Mabasa	D	Poor. Has had several accidents, recently including one major. Watch.
2573	Lawrence Moletsi	E	A consistently bad record with no sign of improvement. Not worth retaining.
3587	Silas Mokoena	—	Too new to classify but so far very unsatisfactory. Is having too many accidents and in addition has a bad disciplinary record. Not worth retaining.
3493	Abraham Ditsi	—	Too new to classify but so far unsatisfactory. Seems to have outgrown his learning period and to be settling down.

This system, though it took considerable work to es-

tablish, has been found very easy to maintain. The records are, in fact, kept up to date by one very competent African clerk. As a system, it has definite practical advantages. Its most important advantage is the rapidity with which it highlights the driver who is running into danger. Any older driver whose accident pattern suddenly changes or any new driver whose learning period seems to be proving unduly expensive is shown up before too much damage can be done. Immediate action can then be taken according to the individual circumstances.

RESULTS OF THE PRACTICAL IMPLEMENTATION OF THE ACCIDENT RESEARCH PROJECT

In assessing the improvement or deterioration in the general accident position of a transport company there are so many factors which might have a bearing on the situation, and which should be taken into consideration, that it is virtually impossible to determine how much credit or blame can be attributed to any particular one. There are, for instance, such factors as alterations in managerial control, changes in the standard of training, or intensified accident prevention campaigns. There is also the important question that if certain measures lead to the pinpointing of bad drivers and their consequent dismissal, these men have to be replaced by new drivers, and that the quality of these new men will have a marked effect on the general accident position.

Note: In point of fact as stated before, the accident research project outlined in this paper has run concurrently with a major research project on the selection of new driver intake by means of psychological tests. In the course of this psychological project, several new and somewhat revolutionary procedures were developed, particularly the use of personality tests such as the Thematic Apperception Test for driver selection. The use of personality tests for driver selection was based on psychological investigations which established the important part played by personality and temperament in accident causation, and also by the successful statistical validation of a specially designed African T.A.T. as an accident predictor. This investigation, the various personality and temperament tests used, and also the results of selecting African bus drivers by this means, will be described in the third paper to be written by the present authors.

Whatever the contributory reasons, the fact remains that a marked improvement has occurred in the accident position of the company since this particular accident investigation was put into operation.

In the Johannesburg area alone, where greater traffic density has been accompanied by an increase of 25 per cent in the accident rate of the motoring public over the last eight years, the company's accident rate has shown a contrasting decrease of 38 per cent.

The following facts concerning the percentages of drivers in the various accident categories are also of interest:

The standards for the new categories were originally set in 1956 on the basis of all the drivers on strength at the time. These standards placed 75 per cent of the current drivers in the C (satisfactory) or better categories, a reasonable working basis.

However, before the new classification system could be put into routine operation, a good deal of statistical verification was still necessary and it was nearly two years before the first accident ratings were published for official use. During that time no significant change had taken place and the percentage of drivers in the satisfactory and better categories was found to be 78 per cent.

Publication of the new accident ratings did not have any immediate effect. In fact they were met with the sort of suspicion that is so often accorded by branch management to head office innovations. However, the opposition died down when it became obvious how accurate the classification system was and how well it could predict each driver's future behavior. When the passing of time showed that a man who had been classified as an 'A' category driver continued to be relatively accident free while an 'E' category driver continued to be accident prone, the practical value of the system was recognized. The bad accident risks were eliminated and replaced by men of a better calibre, scientifically selected. The result is that three years later, instead of the original 75 per cent, the company now has 93 per cent of its drivers in the satisfactory accident categories.

It is apparent, therefore, that a marked improvement has occurred in the company's accident position, particularly over the last few years. Whatever the contributory reasons for this state of affairs, there is no doubt that the new systems of recording the company's accident position and of evaluating its individual drivers has proved very successful.

DISCUSSION

This particular investigation was confined to one transport company and one population, namely urbanized African bus drivers driving for a transport company in two South African cities. Nevertheless this statistical investigation carried out was a very extensive one: the number of subjects (nearly 900) was large; the length of exposure of many of the subjects was long and the records were kept in great detail. What is more, the patterns of accident behavior that emerged were so consistent that it was justifiable to presume that they did not occur by chance, that they had definite statistical significance and that they could be representative of accident behavior in a far wider field.

The present writers feel therefore that in view of the international importance of the problem of road accidents, it would be appropriate to conclude this paper with a discussion on the implications of the findings of this particular research project in the sphere of general accident prevention, particularly amongst professional drivers.

In this study of a large group of professional drivers, all trained to a high degree of proficiency, all driving similar vehicles and all exposed to the same or equalized driving risks, the following significant facts emerged:

That the most reliable statistical indicator for measuring accident liability was the time intervals between successive accidents.

That the frequency (meaning the number and the pattern of occurrence) of a man's accidents was even more significant than the severity of the accidents or the degree of blameworthiness attributable to the driver.

That in a great many cases a learning period, characterized by relatively high accident frequency, was evident in the early stages of exposure (particularly among inexperienced drivers).

That the duration and intensity of this learning period was different for each individual.

That once this learning period was overcome, the rate of accident occurrence in each individual became remarkably stable and that further slow learning through experience was the exception rather than the rule.

That this level of accident liability for each individual was so stable that reliable predictions of future accident behavior could be made on the basis of the evidence of past accident occurrences.

That this stable level of accident liability was different for each individual.

That although factors such as age had a certain effect on accident liability, nevertheless there was a pronounced variation in the accident liability of individuals of the same age.

That in a significantly large number of individuals there was definite evidence of "accident proneness," i.e. they showed a consistent pattern of frequent involvement in road accidents of one kind or another over a long period of time.

That with these accident-prone individuals, remedial measures such as periods of retraining or strong disciplinary action had only a very temporary effect; the improvement, if any, was very brief and they soon reverted to the old pattern of frequent involvement.

That among the "non-prone" drivers—the men whose records showed patterns of few accidents at relatively long time intervals—fluctuations in these patterns were rare and any significant fluctuation could usually be traced to some specific reason such as drink, or severe psychological disturbance, or ill health, or advancing age.

That accident occurrence among the group of drivers studied was influenced by such emotional functions as worry, feelings of insecurity, or dissatisfaction with working conditions.

These findings have significant implications for companies employing professional drivers. They highlight the individuality of accident liability and the need for keeping individual records and for recording each driver as an individual entity.

They indicate also that a man's past record of accident liability is a very good guide to his future behavior. In practice this means that because a man with a good past record is unlikely to deteriorate, his services are valuable and his good record should receive due recognition. But, more important still, it means that the man whose past record has been unsatisfactory is unlikely to improve, punishing him will have very little effect and retraining him means throwing good money after bad. The only practical way of insuring that he does not have accidents is to prevent him from driving.

The findings indicate too, that it is possible to detect a bad accident risk among professional drivers at a relatively early stage. The number of accidents (relative to exposure) in which a driver is involved has been shown to be so significant that any new driver who becomes too frequently involved in accidents, however trivial, should be regarded as highly suspect. Although allowance must be made for a learning period, nevertheless any new driver whose "teething stage" appears to be unduly long or expensive is in all probability not worth keeping.

On the other hand, any sudden deterioration on the part of a good driver is also very significant and can often be remedied by individual attention. It should not be regarded merely as a run of "bad luck"; it is probably symptomatic of personal or domestic problems, or ill health, or psychological disorder, or dissatisfaction with his working conditions.

When it comes to the question of employing professional drivers whose previous records are unknown, or of selecting inexperienced men for training as professional drivers, selection methods based on tests of intelligence and innate skill are unlikely to give any real indication of future accident liability. Accident liability appears to be something so innate in the individual that it is reasonable to presume that it is dictated by the interplay of those functions that make him an individual and distinguish him from other individuals. The only selection precedures, therefore, which are likely to prove successful are those which are comprehensive enough to assess his physical capabilities in relation to such psychological functions as emotional stability, outlook, personality and temperament.

With regard to the application of the findings of this investigation to the general motoring public the present writers appreciate only too well the obvious practical difficulties involved, but feel nevertheless that they do provide food for thought in the planning of safety campaigns. They are particularly relevant to the subject of the issuing or retention of driving licenses, for it would appear that the findings provide even further proof of the fact that certain people are such inherently bad accident risks that they should not be allowed to drive.

However, at present it is usually difficult to stop them from doing so. The case of the transport company in which this investigation was carried out is an illustration in point. This particular company was able to identify the bad accident risks among its drivers and to make a substantial reduction in its own accident rate by refusing to employ these men. But it could take no action whatever about preventing these men from driving elsewhere. Most of them are, in fact, driving privately or for some other firm and are continuing to be a danger to the community.

Individual action is not enough. Action on the part of a higher authority is needed.

The present writers feel that the question of road accidents is assuming such alarming proportions throughout the world that it is becoming increasingly necessary to approach the problem at a level where not only can adequate funds be made available for research on a large scale, but practical effect can be given to the findings of this research.

Readers of the RESEARCH REVIEW are invited to submit letters to the editor commenting on articles appearing in this journal. When it is appropriate, copies of such letters will be forwarded to authors for reply. The original letter and the reply will then be published in the issue following.

INFORMATION REQUEST FOR TRAFFIC SAFETY RESEARCH CORRELATION SERVICE AND ANNUAL LISTING

As a service to researchers and officials in the traffic safety field, the Research Division of the National Safety Council maintains a file of abstracts of contemplated, in process and completed highway safety research projects. The March issue of the RESEARCH REVIEW contains a listing of such projects for the current year.

Summaries of projects are exchanged with agencies engaged in or utilizing safety research and are forwarded to investigators who request such information.

In order to keep the files current, it would be appreciated if readers of the RESEARCH REVIEW would fill out the form on this page and send it to: Murray Blumenthal, Ph.D., Director, Research Division, National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

(For reproduction purposes—please type, or write legibly in pencil.)

Title of Project:

Status of Project: Completed In-Process Contemplated

Beginning Date: Completion Date:

Principal Investigator(s): Official Title Department

Name and Address of Organization:

Summary of Research Project (200 words or less):

Please state the problem under investigation, major hypotheses, the number, location and characteristics of the subjects, the methods of investigation, and results and conclusions or expected outcomes. (If more space is needed, continue on a blank sheet of paper.)

Publication Reference(s) and/or Plans: (If copies of completed report are or will be available to professional public, please mention.)

Submitted by Organization

Metropolitan Life Award For Research in Accident Prevention

The National Safety Council takes pleasure in announcing the selection of J. Stannard Baker as the recipient of the Metropolitan Life Award for Research in Accident Prevention. Baker is director of Research and Development for the Traffic Institute of Northwestern University, Evanston, Ill.

The award was given for Baker's work on a study which was a pioneering attempt to employ an interdisciplinary team in the intensive study of motor vehicle accidents. The project was supported by U. S. Public Health Service, U. S. Bureau of Public Roads and the Automotive Safety Foundation.

A plaque and a check for $1,000 was presented to Baker by Dr. George M. Wheatley, 3rd vice president of the Metropolitan Life Insurance Co., at the annual meeting of the National Safety Council held in Chicago Oct. 16, 1961.

Case Studies of Traffic Accidents

PROBLEM

Accident reports from drivers and police now supply sufficient circumstantial data to guide the administrative phases of traffic accident prevention, but for technical phases we need to know much more about causes than is available from these official reports. Drivers, consciously or unconsciously, are biased in what they report because of their interest in possible attempts to fix responsibility, and police gain most of their information from drivers. Road conditions, such as icy streets, are regularly reported as circumstances without evaluating their contribution to the accident. Driver and vehicle conditions, however, have been so poorly reported that the national standard specifications for report forms no longer require this information.

Because an accident must be studied ex post facto, what is known about its cause is someone's conclusion. Known circumstances are interpreted by the investigator in terms of his knowledge of scientific principles. Neither the knowledge of drivers and police nor the circumstances under which they report lead us to expect their conclusions to be reliable. The main problem therefore was how to learn more about causes from studying accidents. This engenders relevant subproblems such as:

Can an interdisciplinary team invent methods of data collection and interpretation that are more effective than those developed for enforcement purposes?

What observations are necessary and what are the problems involved in making these observations?

Just what is one seeking when he tries to determine cause and how many different contributing circumstances might one have to look for?

What are the limitations and obstacles to determining accurately how an accident happened?

As a by-product of answering these essentially methodological questions, what causes appear when the accidents experimentally studied are "dissected" by such intensive investigation, even though the number of such cases is not large.

If the main question were to be expressed as a formal hypothesis, it would be as follows: an interdisciplinary approach by technically trained people can develop reliable, causal information about accidents by ex post facto study.

METHODS

The problem was attacked simultaneously from several angles.

1. In the hope that a "break-through" in methodology might result from a fresh look at accidents, an interdisciplinary team of an engineer, a physician, and a behavioral scientist—at first a psychologist and later a sociologist — was formed. To avoid "contamination" by conventional dogma, they were recruited from outside the traffic safety field and purposely shielded from published material and courses in accident investigation at the Traffic Institute. Arrangements were then made with the Evanston, Ill., Police Department to summon the team to the scenes of accidents as soon as possible after their occurrence. If individuals involved in an accident agreed to cooperate and if the accident did not involve commercial vehicles or certain other unfavorable circumstances, the team began to ask questions and make observations. Later there were detailed measurements of the road, inspection of traffic control devices, physical examination and psychological testing of drivers or pedestrians, interviews, and partial disassembly of the cars. There was no limit to the time that could be spent on a case. After data gathering was complete, members of the team formed independent opinions regarding the contributing conditions. Later, in conference, they combined their ideas.

Three series of cases were studied. During the two intervening periods, a set of 20 new data-gathering forms were devised, time-space diagrams were introduced as a technique of accident reconstruction, and plans were developed to give more attention during interviews to circumstances of the accidents. Altogether 68 subjects were studied in 51 accidents all in Evanston, Ill. These accidents reasonably represented those in the community.

It was planned to apply the new methods of cause analysis, which were developed during the project, to a longer series of cases, but the work had to be discontinued before this could be done.

Although it was not an approach to the solution of the main problem and the sample was small, the "derived accident factors" for cases studied were tabulated to show what and how many were found.

2. Another approach to the problem was carried on independently by others connected with the project, using data from cases investigated as part of the study material. This approach comprised an analysis of the principal published concepts of traffic accident causation to determine what they had in common and compilation of an "Inventory of Factors Suggested as Contributing to Accidents." The purpose of this work was to develop a classification system which could be used to guide systematic analysis of an accident to determine its contributing factors, and a list of factors which might be encountered in studying accidents.

3. Another approach to the problem was aimed at discovering something about why the most critical step in identifying the cause of an accident often goes wrong. This step is the drawing of conclusions from available data. Two studies were made for this purpose. First, the work methods not only of the team but also of professional investigators for police and insurance companies was studied by the project director. Second, a carefully designed and controlled experiment was made in which 1,214 people of seven levels of technical competence—from club women to traffic engineers—were given facts about a simple head-on collision and asked to determine which car was at fault. The information supplied was varied by inclusion or exclusion of irrelevant information of a psychological character (description of occupants of the cars) and of a physical nature (emphasizing a scratch on the road left by the collision) which gave different forms of presentation. The results were subjected to analysis of variance to determine the effect of the irrelevant information on opinion formation. With some technical groups the experiment was extended by giving longer

time to study the case, and second, giving a different set of instructions.

RESULTS

1. The interdisciplinary approach encountered unexpected difficulties in securing prompt joint activity by the physician, engineer, and social scientist. The very different backgrounds of their disciplines seemed to stand in the way of coordinated attack on a common problem. Initially, the team members insisted on each investigating all aspects independently. More than a year elapsed before members of the team successfully focused their disciplines on case studies rather than applying case studies to their disciplines. Furthermore, the physician and engineer both found available techniques adequate to evaluate the road, the car, and the physical condition of the subjects. But both behavioral scientists sought tests for the slight variations of personality that might make a difference between accident and no accident. They wanted to take time out to develop new instruments for this purpose. Several such tests were, indeed, attempted.

Unquestionably the team was able to analyze accidents for causes more fruitfully than had been done hitherto. The analysis was much more complete than could possibly be done by police without extensive training. But the cost, about $900 per case, and the fact that scientists would not relish such a data collecting job for an extended period, suggest that this is not a practical way to study the tens of thousands of cases necessary to evaluate almost a thousand recognized potential accident factors.

The fresh approach yielded extensions and refinements of data collection and interpretation rather than any breakthrough in accident study methods.

Analysis of the accidents studied resulted in tabulation of the condition factors contributing. Among the 68 subjects studied a total of 289 contributing conditions were identified, an average of 4.3 factors per case. Every case had at least one factor, some had as many as ten. Of these derived accident factors, 102 related to the road, 24 to the vehicle, 117 to the driver or pedestrian, and 40 to the social situation. Of these conditions, 77 were stable attributes and 212 were variable modifiers. The number of factors would have been greater had the same techniques for cause analysis developed during the project been available from the beginning.

2. The analysis of theories of accident causation combined with the practical requirements of accident investigation, resulted in an operational classification of contributing factors based on failure of the trafficway-vehicle-person road-transportation system. A factor was defined as a circumstance which is necessary for the accident to occur but not sufficient by itself to produce an accident. The cause was defined as the combination of necessary factors sufficient to produce an accident. Two kinds of factors were recognized: operational and condition. Operational factors act at three distinct sequential levels: evasive action in the face of actual hazard such as a collision course; strategy relative to potential hazard to make successful evasive action possible, and trip preparation which provides the basis for appropriate strategy. In each level are three sequential action phases: perceiving the situation; decision as to action required, and performance. A failure at any point in this system is the key to an operational factor. Such failure may then be explained by the other kind of factor, conditions. Condition factors are basic attributes of the vehicle, the road, and the person involved. Such attributes may be suddenly or gradually and also temporarily or permanently altered by any one of many modifiers. This system concept for the first time provides a universal classification to accommodate all kinds of factors. It also brings to cause analysis a discipline which forces the investigator rigorously to connect observed system deficiencies with the behavior implied by the results of the accident in a cause and effect relationship.

The inventory of factors classified in this manner lists more than 850 operation failures and conditions believed to contribute to traffic accidents. The list could easily be extended. Innumerable combinations of these factors could cause accidents. Approximately 130 of the condition factors were added to the list by the case studies. Most of the others came from published sources.

3. The experiment to discover "Sources of Error in Deciding How a Traffic Accident Happened" was the only part of the research adapted to a rigorous scientific experimental approach. The hypothesis that technically trained people such as engineers, and experienced investigators such as insurance adjusters and police, would be more successful in concluding how an accident occurred was not supported. With or without irrelevant data, these subjects did not do significantly better than housewives or college girls. Only 54 per cent of all of those given the problem without irrelevant data came to the correct conclusion. Emphasizing the irrelevant physical data (scratch in the pavement) reduced the correct conclusion significantly from 54 to 34 per cent. Describing the occupants also made a difference. With the juveniles in the car at fault, 59 per cent of the replies were correct. When they were in the other car, only 44 per cent were correct. An analysis of variance of these data indicated the statistical significance of the findings. It was also found that, among professional investigators, more time to work on the problem gave a significantly higher proportion of correct solutions, and that the manner in which the subject was instructed also had an effect.

A special analysis was prepared on "Limitations of Accident Reconstruction." This is a guide for people attempting to infer from available data how an accident occurred by applying principles of dynamics or other sciences. It specifies the conditions which limit reliability of conclusions and describes approaches to evaluating this reliability.

DISCUSSION

The experience reported with the fresh look and the interdisciplinary approach is, of course, based on the experiment with only one team. Different experience might result under other circumstances. However, it seems clear that such teams are not practical for collecting the great masses of data required for a full understanding of accident causes. It might be practicable to have specially trained police officers gather data for interpretation by specially trained scientists, especially if study were focused on a limited number of factors.

The operational concept of accident causation should prove very useful in any systematic study of accident causes, especially a study with a clinical approach. Its use would unquestionably make requirements for data collection more

exacting and would require much more rigorous thinking in drawing conclusions concerning causes.

The study on sources of error in determining how an accident happened points clearly to the need for special training of any persons who propose to undertake clinical studies of accidents to determine causes. Furthermore, it has important implications with respect to the degree of adequacy of our judicial system for determining negligence in accident cases. This experiment indicates that often juries will not have the necessary technical background to draw proper inferences from evidence presented to them.

Fewer than 100 cases constitute no basis for evaluating the importance of almost a thousand factors which are thought to contribute to accidents. However, these cases do give new insight into some aspects of accidents, for example, the extreme importance of inference by drivers about what other road users will do, the difficulties drivers face of coping with competing hazards, the very slight deficiencies of the elements of the highway transportation system which will be enough, in combination with other variables, to make the difference between having and not having an accident.

SUMMARY

Helpful official accident reports from drivers and police contain almost no reliable information about accident causes. The problem in this pilot study therefore was to find out what might be learned about causes by more intensive and scientific study of accidents.

A team consisting of an engineer, a physician, and a behavioral scientist went to accident scenes minutes after the occurrence and later spent days in examining car, driver and road. Concurrently, other research people developed an operational concept of accident causation and conducted an experiment on 1,241 subjects to determine the effect of certain irrelevant information on conclusions about causes.

The interdisciplinary team studied 68 subjects in 51 accidents and identified a total of 289 contributing car, driver, and road conditions, or 4.3 conditions per case. They developed a set of 20 data-collecting forms and short-cut methods for preparing time-space diagrams for accidents. But an interdisciplinary team was considered too expensive to be practical for long term study of the thousands of factors thought to contribute to accidents. The need for investigator training was emphatically indicated by the fact that technically trained people were not significantly more successful than laymen in determining who was at fault in a head-on collision for which adequate data for determining fault were supplied to the subjects tested. However, irrelevant data relating to the results of the accident and occupants of the vehicles did have a statistically significant effect on conclusions relating to how the accident occurred.

The results of this study should be useful as both a practical and a theoretical guide to the future development of accident studies for accident prevention purposes.

ADDENDUM

Recommendations

Although recommendations are not, strictly speaking, within the purview of a report on research, they are appropriate for a pilot study. Therefore, the following brief suggestions are made with respect to future efforts to gather more information about how and why accidents happen. These suggestions are limited to what seem practical at present rather than what might be ultimately desirable.

1. On accident report forms police and drivers should not be asked to state a "cause" even in terms of law violations, only facts should be recorded. Drivers are naturally biased but police will sincerely attempt to report opinions. However, with their very limited scientific training, police tend to name some law violation as the cause, accepting that which is a stereotype for obvious circumstances. For example, rear-end collisions with both cars moving are nearly always "caused" by following too closely even when the rear driver fell asleep. These stereotypes may obscure real combinations of contributing factors. In other words, police tend to report common expressions for the symptoms of accidents rather than diagnoses of the causes. Tabulation of such superficial conclusions tends to sanction them and so perpetuate misconceptions.

2. Encourage development and tests of measures sufficiently sensitive to show whether and to what degree specific skills, attitudes, and emotions are likely to have contributed to an accident involving certain observable circumstances. Whereas careful examination of the car and road will usually reveal deficiencies which could have contributed to an accident, available methods of examining drivers for other than physiological conditions are less likely to do so. Developing such psychometrics may be difficult, but the need for greatly improved techniques for this purpose is vital. Without them it will be difficult to determine whether such personality traits are important or unimportant contributors to accidents.

3. Institute a program in which a number of agencies already having first hand access to accident information (for example, police and insurance claims adjusters) participate in a series of studies of selected accidents such as, those involving tire failure, rear-end collisions, and running off the road on curves. A program of this kind would involve a minimum amount of training for both those who collect the data and those who study it. To be effective this should be a program as contrasted to a project to enable those participating to develop insight with continuing experience and to apply such insight in subsequent accident studies.

4. Consider development of a supplementary report to be used by selected investigators to gather factual data on a random sample of accidents visited (for example, every tenth accident). Such data would supply, without excessive cost, supplementary material for statistical study. This supplementary data might include information such as the nature of the trip, kind of road, more precise description of the vehicle, land use in the vicinity or severity of the accident, and some systematic record of the recollection of the driver involved regarding his discovery of the hazard and the action which he took. Such information would be used in driver training and education to mold proper attitudes toward the driving situation.

To summarize, in studying accidents there are a large number of possible factors to be considered. Securing precise and complete information after the event is difficult. Therefore, drawing conclusions about the complete combination of contributing factors to an individual accident is such exacting work that it probably would not be profitable until people are available who have had highly specialized training for the task.

Roadside Design For Safety

by K. A. Stonex

Kenneth A. Stonex, assistant director of the General Motors Proving Grounds, Milford, Mich., joined the organization in 1934.

Majoring in mathematics, Mr. Stonex received a B.A. degree from Michigan State College in 1933 and an M.A. degree from the University of Michigan in 1934.

He has been active in technical societies and as a speaker on mathematical phases of automotive testing and testing facilities. Many of his papers have been published, and he won the Highway Research Board Award for 1960 for "Roadside Design for Safety."

Mr. Stonex is very active in several committees and departments of the Highway Research Board of the National Academy of Sciences, National Research Council. He also is affiliated with various committees of SAE, American Standards Association, Automobile Manufacturers Association, and others.

The significance of the roadside in the highway safety problem is apparent from the National Safety Council's statistics. Year after year, between 30 per cent and 35 per cent of the highway fatalities—12,000 to 13,000—in the country occur in non-collision accidents, most of which involve vehicles leaving the roadway.

This factor is second only to the two-vehicle collision as the most important and deadly. A great deal of engineering design effort is being devoted constructively to reduction and elimination of the two-car collision. The divided highways of the Interstate System, the turnpikes and the expressways, grade separations, one-way streets, and signal installations and stop signs on intersections at grade are all attempts to eliminate this type of accident. Intensive driver training, public educational and enforcement programs are corresponding efforts in other fields.

In the policies on geometric design of the Interstate System, recognition is given to the importance of roadside hazards by the adoption of enlightened standards of roadside design with respect to slope, ditch cross-sections, and elimination of obstacles. In reconstruction and modernization of existing roads, some attention is given to this problem, but one cannot help but feel that the minimum standards are applied all too frequently in construction of portions of the Interstate System; one cannot help but feel that too little emphasis is given to the elimination of roadside hazards on primary and secondary and rural roads, even when they are being reconstructed.

It is the intention of this paper to discuss the problem in general and to give a number of specific examples of roadside hazards drawn in a large part from experience with the proving ground road system. It is the further intention to discuss some research results from which specific design criteria for roadside slopes and ditches are derived. The stability factors of passenger cars are related to observed roadside characteristics, especially with respect to the slope of roadsides and the coefficient of friction of the roadside surfaces. Some discussion is given to the hazards involved in conventional light poles and sign posts, with suggestions as to how this type of hazard may be reduced or eliminated. In addition, further observations on full-scale guardrail impact tests are given to supplement earlier publications on this subject.[1] Particular emphasis is given to guardrail end installations.

Some of the examples of roadside hazards have been discussed previously; they are repeated here as background and to give appropriate emphasis to the problem.[2] [3]

Today the proving ground road system includes about 62 miles of all types of surfaces common to those of the public highway; portions of this system with the highest traffic volume were completed by the middle 1930's. During the past 35 years, over 200 million test miles have been operated, and the current rate is about 40,000 miles a day, or 10 million miles per year.

At the proving ground the normal standards of shop safety have always been employed. Thirty-five years ago, the attitude about industrial accidents, quite generally, was that accidents were something which would happen, and that we had to learn to live with them. The industrial safety engineer has shown that is not so. He has shown that accidents are preventable, and that accidents in the plant usually come about because of some human malfunction. Recognizing that, while accidents are preventable, some will not be prevented, he provides all safeguards he can imagine for all types of carelessness and inattentiveness which people may show so that the effect of an accident may be minimized. When, a few short years ago, we began to apply the concepts of the industrial safety engineer in our consideration of the proving ground safety program, it became evident that the most serious potential hazards lie in the operation of our vehicles on our road system, because both the masses and the speeds of cars exceed those of any of the other machines with which we work.

Generally speaking, the proving ground road system was quite well developed 20 years ago. In construction, the design standards which prevailed generally at the time of construction were used, and our practices were comparable with those of the state highway departments. The basic elements of highway safety were considered with admirable foresight in the design of the road system at the estab-

---

Originally presented in full at the 39th annual meeting of the Highway Research Board, Washington, D. C.

lishment of the proving ground, and one-way traffic, limited access, and avoidance of intersections of main test roads at grade has always been the policy. Thus, the basic design of the system avoided many of the types of accident which are now causing such great concern in the public transportation system. At the time, this approach was unique in its enlightenment and progressiveness.

As we reviewed our accident statistics, we found that, during the six calendar years 1953-1958, inclusive, covering approximately 65 million test miles, there was a total of 236 accidents, of which 72 per cent were off-the-road.

Our first and most obvious concern was to determine the reasons why drivers left the road. In many cases, the driver went to sleep. In other cases, he was obviously inattentive. Educational programs were undertaken, reprimands were given, and in the more flagrant cases, drivers were discharged.

In spite of all of this, it became evident that drivers do leave the road, infrequently, it is true, but all too often, simply because they are people, and suffer normal human fallibility.

A further consideration led to the conclusion that it was not possible to keep all drivers on the paved surface all the time. *One of the fundamental principles of safety engineering is to anticipate every possible type of accident which may occur because of machine failure or human failure and then to establish safeguards to minimize the hazards or injury which may result when such a failure occurs.* When we looked at our road system from the same point of view, we were considerably disturbed to find that design standards provided little or no safeguard in the event that there should be a failure of some type. Our predecessors had pioneered in safety engineering by taking fundamental steps to avoid accidents, but they did not apply the second concept of the industrial safety engineer, to provide all safeguards in the event that an accident occurred because of human fallibility.

When we realized that our roadside design did not incorporate the safety features common to our machine shop, garage and maintenance tools, we sought to make amends at the earliest possible time by using the experience of other people. We made immediate comparisons with public highways in the adjacent area; we found that the public highway system repeated most of the shortcomings of our own road system. We looked at highway construction in other states, at the turnpikes, even the newest components of the Interstate System, and we found even there a lack of safeguards which would not be tolerated in any modern industrial operation. Almost every mile on any of these roads has one or more places where the occupants would suffer serious or fatal injury if the vehicle left the road at normal highway speeds.

An approach to the problem of safe roadside design from the attitude of the industrial safety engineer became our primary interest in providing the proper safeguards to our employes operating on our own road system. Every roadway accident includes as factors the driver, the vehicle, and the highway; and these factors were considered properly in our approach to our problem.

Our drivers are adult males in good health; they are selected on the basis of average or above competence and on the characteristics of desirability in an employe; they are all qualified drivers with several years of experience in normal highway driving; and it is fair to assume that they compare with the upper strata of drivers in the traffic stream on the basis of these characteristics. They drive on a closed road system with favorable geometry, relatively low traffic volumes, controlled access, one-way operation, and under relatively close supervision. Extensive training and educational programs have been conducted. Our minds are not closed to the possibility of more effective ways of improving driver performance; we have exhausted the obvious solutions and we have tried some which are not obvious. In spite of this, during the last six calendar years, we have had 170 off-the-road accidents.

The business at the proving ground is the development of automobiles. We are familiar with the scrupulous attention given to safety in design and manufacture, and we are confident that the current automobiles well maintained are practically free from hazardous failures in service.

Our confidence in the quality of the vehicles and our experience with the fallibility of the drivers left us with the firm conviction that the major deficiency in our effort to eliminate accidents was the failure to devote sufficient attention to the road itself. In our case, the concept of the original traffic pattern practically eliminated two-vehicle collisions and confined the problem almost entirely to the roadside.

COMMON ROADSIDE HAZARDS

When one adopts the safety engineer's attitude and concepts, the most dangerous situation perceived immediately is that of obstacles adjacent to the road, that is, close enough to the traveled surface so that the driver who has lost control of his vehicle temporarily will strike the obstacle before he has an opportunity to regain control. On our road system, and on nearby public highways, the most obvious obstacles are trees. Trees are desirable and beautiful, and in the early days of the proving ground, we frequently modified the alignment so that a large, beautiful oak might be saved. However, a review of any newspaper shows that trees contribute almost every day to the statistics of injury and death.

Trees have played a part in the more serious proving ground accidents. The severity of an impact at normal speeds is indicated in Figure 1. This car was driven by remote control into the tree at 35 m.p.h.; it was damaged seriously and it was evident to anyone who witnessed the accident that occupants of the car would have been seriously injured and probably killed. To the safety engineer, the immediate conclusion is that trees close to the roadside must be eliminated systematically. Fortunately, with modern equipment this is practical and relatively inexpensive. After the trees are removed and the roadside smoothed with a grader, no possibility of serious accident in this area remains.

This situation has its direct counterpart in the public

Figure 1—35 m.p.h. car-tree impact by remote control.

highway system; on some major highways of relatively modern design, there are trees so close to the road as to be lethal obstacles, and in fact, on some of the newest highways, small trees are being planted as part of the landscaping program. As a result, in all too few years, the small trees will grow into big ones; significant hazards being cultivated immediately adjacent to the edge of the road.

Beauty is possible without large trees, or with trees well in the background; in exceptional cases, well designed guard-rail installations may be used if speed is well regulated.

On many of our city streets and even some of our rural highways, there are man-made obstacles in the form of utility poles and light poles immediately adjacent to the paved surface and signs to guide the traveler.

Conventional light poles are self-supporting structures normally erected on a concrete base and designed to withstand winds of hurricane velocity. Unfortunately, they become roadside obstacles of important dimensions. As a compromise, we have proposed use of a tripod structure constructed of light tubular material with shear mounts flush with the base.

This design was evaluated in a full-scale test. Figure 2 shows three frames from the motion picture record of this test. The car passed through beneath the pole with negligible impact and only superficial damage; one leg, whipping during the collision would have injured occupants of a convertible, but the design can be modified to control this.

Standard roadside signs, mounted at 42 in. above the pavement, are also a hazard. In a collision at 40 m.p.h. a sign of this type pierces the windshield partially and showers the front passenger compartment with glass. At higher speeds, the sign would not drop so far and occupants would find themselves running into a 25 lb. sign at whatever speed the car was traveling.

When the sign is mounted at 60 in., the car passes beneath harmlessly. Roadsigns at the proving ground are being relocated at 66 in.

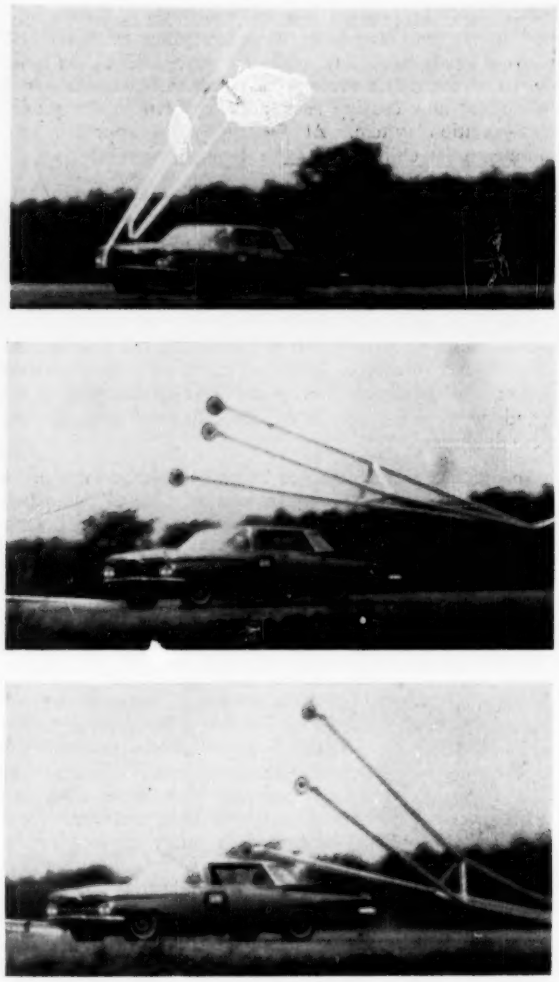

Figure 2—Full scale test of low-impact pole.

DITCHES

In all parts of the United States, it is necessary to provide some type of drainage system along the road to carry off surface water. These ditches are effective for carrying off the water but they may present a very serious hazard.

Figure 3 shows a typical situation on many miles of rural road; it doesn't take a safety engineer to recognize the seriousness of the inevitable accident when some driver becomes inattentive or falls asleep and leaves the road at this point.

Unfortunately, these practices are carried over to new roads; sharp V-ditches are still being graded almost immediately adjacent to the traveled path of roads being built according to the Interstate System's standards.

In some cases, careless inspection procedures or lack of detail in construction leaves a mound unnecessarily. On rural roads, additional right-of-way must be procured or agreements with the abutting landowners made to

abolish such ditches and banks. However, on portions of a modern road system where adequate right-of-way is available, such construction is intolerable to the safety engineer.

Figure 3—Typical ditch on secondary road.

The severity of ditch impacts is indicated by Figure 4, which shows a remotely controlled car driven off a road through a ditch with a 2:1 backslope. The car was severely damaged, and it is evident that the occupants would have suffered serious injury, at least.

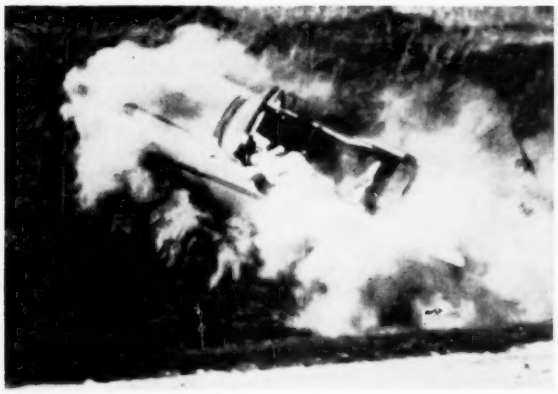

Figure 4—Impact test, ditch with 2:1 backslope.

Figure 5 shows a much milder degree of severity when the backslope is 4:1, in this case, the car climbed the bank with a rather minor impact, and the injury and damage would have been negligible.

The desirability of ditches with flat bottoms and smooth contours and flat slopes has been discussed before but no design criteria have been given. Some preliminary experimentation showed that a car could be driven through a flat ditch with a wide rounded bottom at 60 m.p.h. with ease and comfort.

Figure 5—Impact test, ditch with 4:1 backslope.

DITCH TESTS

In the test above, it was not clear whether the value of the slope and backslope, the width of the ditch bottom, or the depth of the ditch contributed most significantly to the severity of operation. We made a series of tests to evaluate the severity of crossing a ditch as a function of speed and ditch cross-section elements. In the initial series of tests, a ditch was dug in conformity with the Michigan State Highway Department standards for a median ditch on a divided road. Cars were driven through the ditch at moderate speeds; the driver noted the subjective severity as speed was increased and measurements of "vertical" accelerations were made so that the numerical values could be correlated with the driver's sensations up to the point where the operation became so severe it was unsafe. Remotely controlled tests were continued at increasing speeds through the point of minor to severe damage to the automobile; by extrapolation some estimate may be made of where serious or fatal injury may be produced.

Intuition suggests that a ditch cross-section should be of some curved form to minimize impact; as the suspension system deflects under impact, the unsprung mass of the car will follow a curved path. If the transition from the side slope to the bottom of the ditch is gentle enough that the bumper does not dig in, the unsprung weight and the sprung mass of the car should have a continuous, curvilinear motion. The simplest to consider would be a circular motion as indicated schematically in Figure 6.

If the ditch cross-section is circular with radius r, the

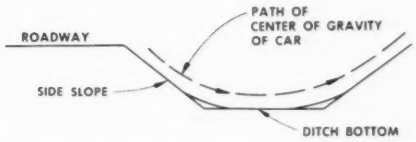

Figure 6—Schematic path of car center of gravity through ditch.

projection on the path at which the car may run through the ditch becomes elliptical in form; the path will make some angle with the axis of the road, possibly up to 20° or more. The projection of a circular cross-section on a path at angle of 90°—ϕ from the axis of the road has this mathematical form:

$$\frac{t^2}{r^2/\cos^2\phi} + \frac{y^2}{r^2} = 1$$

which is an ellipse in the y-t plane, with major axis—$r/\cos\phi$, minor axis—r, where 90°—ϕ = angle between path of car and axis of ditch. Figures 7 and 8 indicate how this projection is made.

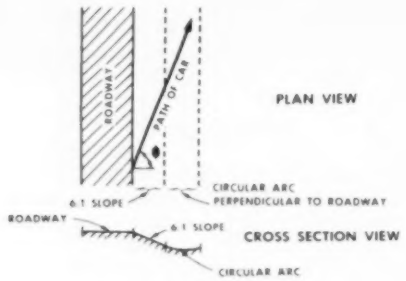

Figure 7—Plan and section, ditch test.

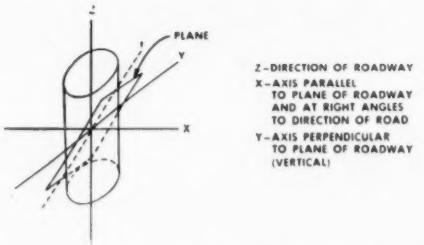
Z
PLANE
Y
X
Z-DIRECTION OF ROADWAY
X-AXIS PARALLEL TO PLANE OF ROADWAY AND AT RIGHT ANGLES TO DIRECTION OF ROAD
Y-AXIS PERPENDICULAR TO PLANE OF ROADWAY (VERTICAL)

Figure 8—Projection of circular cross section on car path through ditch.

With a given ditch cross-section, the radius of curvature may be estimated graphically, and with the speed arbitrary, the value of the radical acceleration can be computed.

In order to verify the analysis and to develop values of radical acceleration or severity which could be tolerated, three test ditch sections were constructed as shown in Figure 9. Two sections with a 4:1 slope are taken from the Michigan State Highway Department standards for a median ditch; these have ditch slopes of 4:1 with varying width of the bottom and varying depth to provide longitudinal drainage. Section 3 has the slope and backslope of 6:1 and the depth varying from 4¼ to 4¾ ft., with an 8 ft. wide bottom.

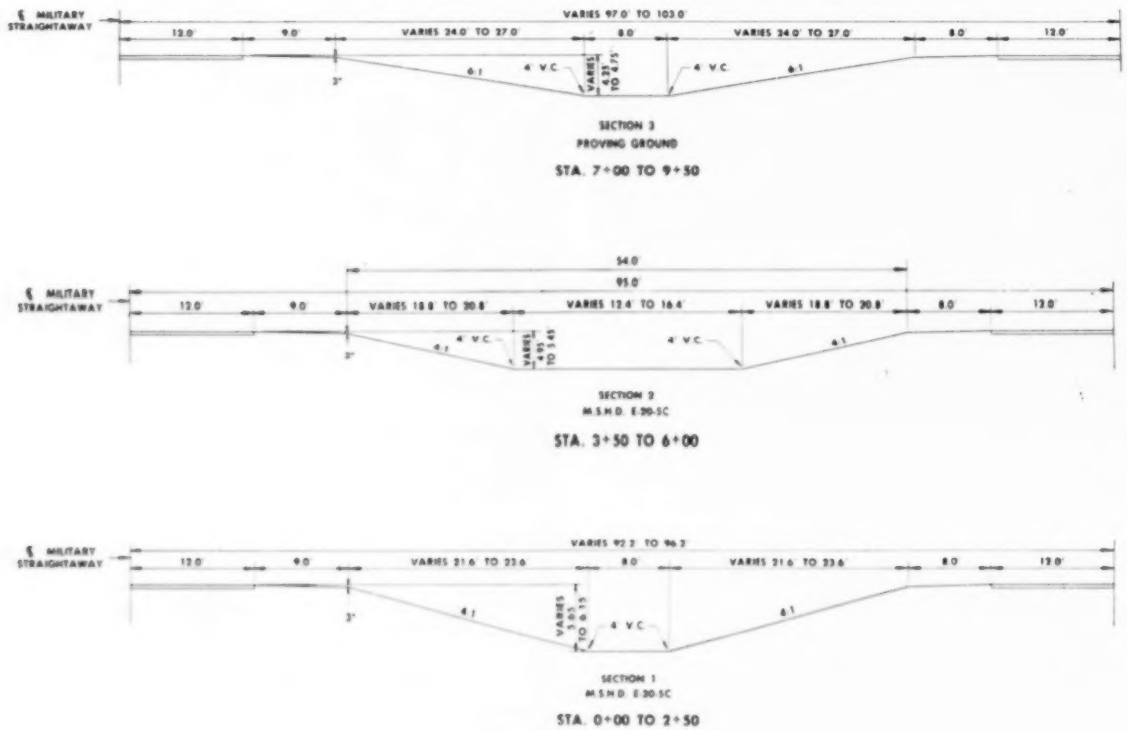

Figure 9—Test ditch cross sections.

Typical values of the normal or vertical accelerations were computed from the test sections of 6:1 slope which are shown in Figure 10.

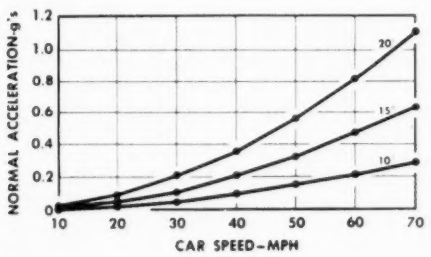

Figure 10—Normal ("vertical") acceleration computed for Ditch Section 3 with 6:1 slopes and an 8-ft. bottom.

The tests were conducted by laying out angles between the car path and axis of the ditch of 10°, 15°, and 20° and by driving the car through the ditch at increasing increments of speed. During each test, recordings were made of the normal acceleration, and the driver's opinion of the severity was noted. Tests were conducted up to the point of extreme discomfort, and an estimate was made of the tolerable value of normal acceleration. It should be noted here that considerable training was involved and the test engineer developed a considerable resistance to this type of operation. This is an experience of considerable severity at the higher speeds, and it may be anticipated that the unwary driver will suffer severe psychological damage before he suffers physical injury. Because of his natural alarm, he is apt to lose control of the car and precipitate an even more serious accident.

After the practical limit of driver tolerances have been reached, test cars equipped with remote control devices were operated in a limited series of tests to determine, if possible, the severity at which structural damage began to appear. It was intended to continue the tests up to the point where we assumed that serious injury would result to the passengers. A limited number of tests were made; these are not considered to be significant, because there should be no serious interest in a ditch section where the severity is beyond the driver's tolerance.

The test data consisted of the values of acceleration measured by a transducer carried on the car such that it measured the accelerations approximately normal to the longitudinal axis of the car and recorded them on an oscillograph; car speed was recorded simultaneously.

Figure 11 is a typical oscillogram from these tests. The upper trace indicates car speed; in this test it was 51 m.p.h. The second trace from the top shows an indication of the time during which the car was passing through the ditch as noted by the driver; this is indicated by the slightly elevated portion of the second line from the top extending across the middle two-thirds of the chart.

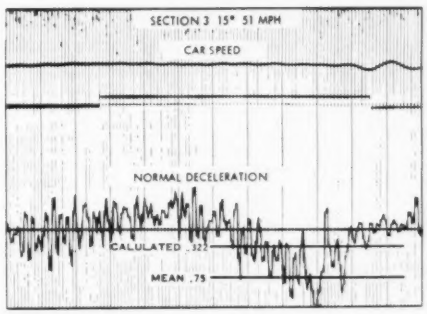

Figure 11—Oscillogram showing ditch test results.

The bottom trace shows the acceleration recorded; as the car enters the ditch, the acceleration is slightly above the zero line, or negative, probably from the effect of going over the vertical curve. The acceleration increases fairly rapidly and during the most severe portion of the passage through the ditch it has a fairly high level which persists for approximately 0.2 seconds. The mean value indicated during this portion of the passage through the ditch was approximately 0.75 g.

The value calculated by assuming the reasonable path of curvature from the projected cross-section of the ditch was 0.32 g.

This relationship between the calculated value and the typical value measured is representative of the conditions found on most of these tests. This chart indicates that, during such tests, we observe values in the range of those calculated, but we also observe values persisting for an appreciable length of time which are considerably higher than those calculated; in the severe cases, of which this is an example, the observed values are nearly twice the calculated values.

This is easy to understand; the suspension system of an automobile will bottom under the values of vertical acceleration which are relatively mild in the framework of reference of these tests. When the suspension system bottoms, vertical forces are transmitted through the rubber bumpers which have a much higher rate than the car springs and a rate which may increase considerably as the deflection is increased; consequently, an impact severe enough to bottom the suspension system will introduce non-linearities for which no provision is made in the calculations and, indeed, which would be difficult or impossible to compute directly by simple means.

Figures 12 and 13 show the comparison of calculated and measured values on ditch sections 3 and 1, respectively, as a function of speed for an angle of attack of 20°.

It will be noted that at the relatively mild conditions at 10 m.p.h., there is reasonably close agreement between the observed and calculated values but that the difference between them increases rapidly as the speed and, consequently, severity of the test increases. It may be noted also that the values of both the computed and measured decelerations increase as the angle

of attack increases; thus a 20° angle of attack at 50 m.p.h. where the computed value is approximately 0.56 g. the observed value is approximately 1.1 g's on the tests on ditch section 3 (Figure 12).

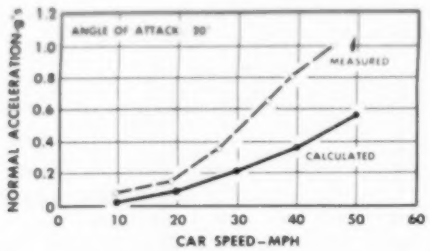

Figure 12—Comparison of calculated and measured accelerations on Ditch Section 3 with 6:1 slopes and an 8-ft. bottom.

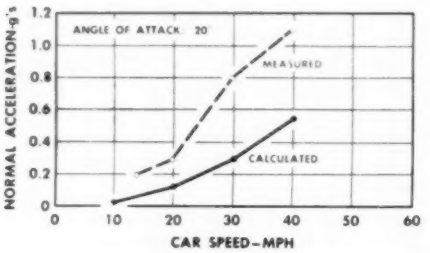

Figure 13—Comparison of calculated and measured accelerations on Ditch Section 1 with 4:1 slopes and 8-ft. bottom.

Somewhat comparable results are shown in Figure 13 in the tests on ditch section 1; the differences between the observed and computed values are even greater. The observed severity of tests was somewhat greater on ditch section 1 and the limiting speed was approximately 40 m.p.h., compared with approximately 50 m.p.h. on Ditch Section 3.

The measured values indicated that the observed severity is approximately twice that of the calculated value under the more severe conditions.

Thus it is apparent that none of the three ditch sections tested would be acceptable for a primary road or a road where speeds above 50 m.p.h. might be anticipated.

Driving experience at moderate speeds indicates that the severity of impact begins to become uncomfortable at approximately the point where the suspension bottoms, and it approaches the intolerable level when the bumper strikes the ground. At higher speeds, it would be expected that even minor contact with the ground would be injury-producing; therefore, this is a condition which the ditch design should avoid. There is some evidence that suspension systems will bottom heavily under normal vertical accelerations in the order of 0.5 g's which appears to be in the range in which the calculated severity of operation is a first approximation to the average values observed.

Design criteria might therefore be based upon the development of ditch cross-sections which, when projected at reasonable angles of attack, would yield path profiles such that the curvature of the path of the center of gravity could be estimated reasonably accurately and first order approximation to vertical acceleration computed. Conservative design criteria should provide that calculated values of vertical accelerations should not exceed 0.5 g for a car passing through a ditch at an angle of 15° under the anticipated speeds of operation. This would assure reasonably comfortable operation at the design speed and provide a slight margin of safety for the driver who may have been unwise enough to exceed the design speed and unfortunate enough to leave the paved surface at 15° or even some higher angle.

The most important element of the ditch section design in controlling the severity is the length of the vertical curve between the side slopes and the ditch bottom. Obviously the radius of curvature is the controlling element; for design purposes, however, it is much simpler to use a circular vertical curve and employ criteria based on vertical curve length.

Figure 14 defines the elements which are considered in the development of criteria.

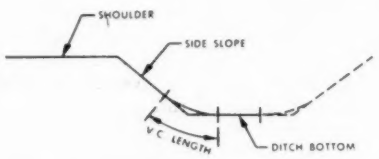

Figure 14—Schematic elements considered in the development of criteria.

Figure 15 shows the relation between vertical curve length and the ditch slope for the arbitrary conditions of the speed of 65 m.p.h. and angle of attack of 15°, which will provide a severity or normal acceleration of 0.5 g. To be noted is the rapid increase in required length of vertical curve as the slope increases.

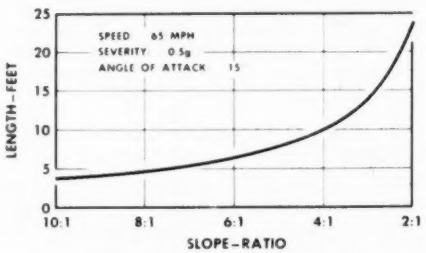

Figure 15—Vertical curve length as a function of ditch slope for severity of 0.5 g's at an angle of attack of 15 degrees.

Figure 16 shows the influence of the angle of attack on vertical curve length for the arbitrary conditions of speed of 65 m.p.h. and a ditch with a slope of 6:1 which will produce a severity or minimum accelera-

tion of 0.5 g. From this it will be noted that the severity increases much more rapidly than the angle of attack.

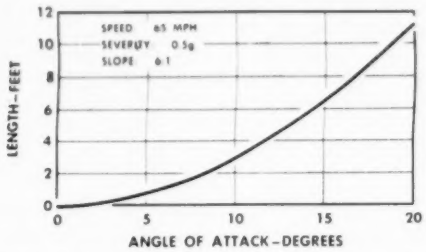

Figure 16—Vertical curve length as a function of angle of attack for severity of 0.5 g's on a slope of 6:1.

The importance of the vertical curve as a design element of the ditch section is emphasized by Figure 17 which shows variation in severity with vertical curve length; conditions assumed are 15° angle of impact, 65 m.p.h. and 6:1 side slope. The vertical curve cannot be left to chance in design, construction, or maintenance.

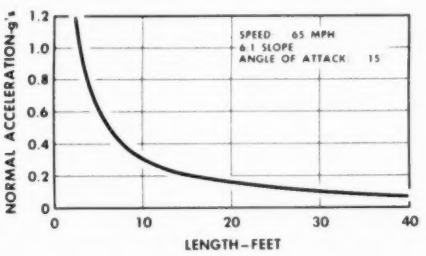

Figure 17—Variation in severity with ditch vertical curve length.

This concept of roadside safety for highways at current operating speeds provides that obstacles are cleared for a reasonable distance from the edge of the pavement to provide maneuver room for the driver who leaves the pavement, and that the roadside is traversable so he can maneuver satisfactorily; obviously the driver will be unable to control his car if the roadside is so severe that the car is damaged or if he is injured or even severely shaken up or alarmed.

ROADSIDE SLOPES

There are little data upon which to base design criteria of the value of the side slopes on fill sections. In some cases, it is obvious that the slope is too steep, or that the transition from the side slope to natural grade was too abrupt. In many cases, we find on relatively flat, gentle slopes that the car slides rather than rolls over and in certain cases, the car may roll over.

The force and moment systems on a car sliding down a side slope are indicated in Figure 18. Here W equals the weight of the car, T is the tread, H the center of gravity height, Θ the angle of inclination of the slope, and F, the sum of the gravitational component and ground reaction or impact reaction against an obstacle at the point where the weight on the upper wheel, W_u, approaches zero. The equilibrium of

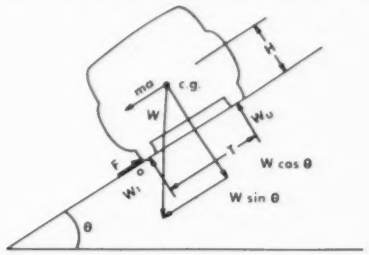

Figure 18—Force and moment relations when car sliding down side slope is decelerated.

force components parallel to the slope of the plane are given in Equation 1, the equilibrium of normal force components by Equation 2, and the equilibrium of moments by Equation 3:

(1) $\Sigma F_x = F - (ma + W\sin\Theta) = O$

(2) $\Sigma F_y = W_1 - W\cos\Theta$

(3) $\Sigma M_o = \frac{T}{2} W\cos\Theta - H\,(ma + W\sin\Theta) = O$

From (1)

(4) $F = ma + W\sin\Theta$

From (4) and (3)

(5) $\frac{T}{2} W\cos\Theta - HF = O$

(6) $F = \frac{T}{2H} W\cos\Theta$

(7) $f = \frac{F}{W} = \frac{T}{2H}$, where $\Theta = O$, and where f = the coefficient of friction or coefficient of ground reaction. Thus on a level road the coefficient of ground reaction which will balance the $\frac{T}{2H}$ car about the reacting wheel is equal to the ratio $\frac{T}{2H}$, where T = tread width and H is the center of gravity height.

Equation 6 shows that, on a car sliding down a slope, the ground reaction force necessary to tip it over is proportional to the cosine of the angle of inclination of the slope, and that consequently the reaction force against the wheel required to tip the car over decreases as the angle of inclination of the slope increases. It should be noted further that the ratio of the horizontal and normal forces, F/W, may be a coefficient of friction or a coefficient of ground reaction required to give this equilibrium of overturning moments and that the value of this reaction is dependent upon the tread width and the center of gravity height as expressed in Equation 7. On a level road, for example, the car will overturn when the coefficient of friction exceeds the ratio of the tread and twice the center of gravity height.

The value of the deceleration which must be provided by the friction or ground reaction on the side slope to overturn the vehicle may be determined from the relations above.

Solution for the deceleration, a, gives:

$$(8)\quad ma = \frac{T}{2H}W\cos\theta - W\sin\theta$$

$$(9)\quad \frac{Wa}{g} = \frac{T}{2H}W\cos\theta - W\sin\theta$$

$$(10)\quad \frac{a}{g} = \frac{T}{2H}\cos\theta - \sin\theta$$

$\frac{a}{g}$ is the deceleration in gravity units or "g's"; it is in the same units and magnitude as f in the equation:

$$f = \frac{T}{2H}\ (\text{Equation 7})$$

The effect of roadside slope on the deceleration provided by the friction or ground reaction on the deceleration required to trip the car is shown on Figure 19 for an arbitrary angle of attack of 25°, where a value of $\frac{T}{2H}$ representative of current automobiles is considered.

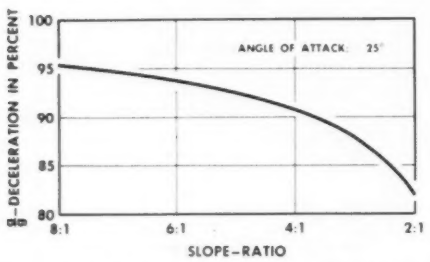

Figure 19—Effect of roadside slope on "tripping" deceleration.

It shows, for example, that deceleration provided by the ground reaction and the coefficient of friction of the slope required to tip the car over is reduced by about 6 per cent below that required on a level road on a slope of 6:1; on a roadside slope of 4:1, the tripping deceleration required to overturn the car is reduced by 9 per cent; on a 3:1 slope by 13 per cent; on a 2:1 slope by 18 per cent. Figure 19 means, then, that it is easier to tip a car over on a steep slope than on a relatively flat slope.

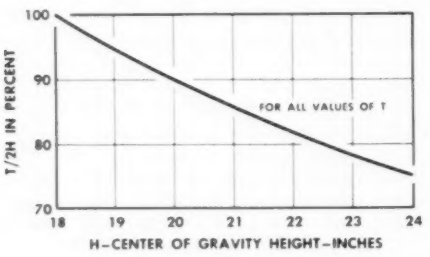

Figure 20—T/2H as function of H and T.

As computed approximately for static conditions, current automobiles have an average stability factor of about 1.4 with some small variations related to different design approaches.

The effect on the stability factor, $\frac{T}{2H}$, of variation in T and H, the tread width and center of gravity height respectively, is shown on Figure 20 for all treads in the practical range and a range in center of gravity height from 18 in. to 24 in. The effect of lowering the height of the center of gravity is of more importance on this variation than is the effect of changing the tread. Figures 21 and 22 show the rates of change of f with T and H, respectively. The derivative of this function with respect to T, $\frac{df}{dT} = \frac{1}{2H}$, is independent of T, indicating that f decreases as the reciprocal of H of all values of T. On the other hand, the derivative of f with respect to H, $\frac{df}{dH} = \frac{-T}{2H^2}$, is inversely proportional to the square of H, the center of gravity height, so that the contribution of H to the stability index varies as the negative reciprocal of H^2.

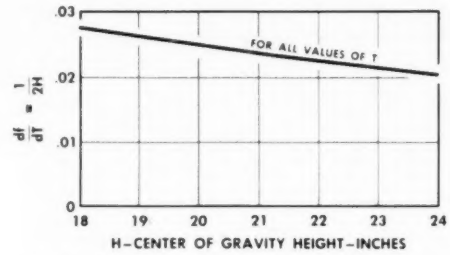

Figure 21—Rate of change of f with respect to T.

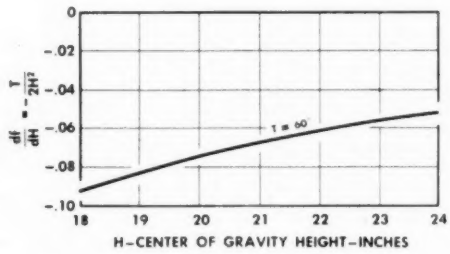

Figure 22—Rate of change of f with respect to H.

The relative stability of the current cars has been achieved largely by virtue of low center of gravity height. In passing, it should be noted that reduction in the center of gravity height means inevitably that the driver's position in the car will be lowered and consequently that the driver's eye height is also lowered.

In other papers, some on this program, the trend in driver's eye height and its relation to crest vertical curve passing distance is discussed.[4,5,6]

It should be clear, however, that the reduction in eye height occurs somewhat in proportion to the decrease in center of gravity height and that the stability of the cars is increased approximately as the inverse square

of the reduction in driver's eye height, that is, as the square of the decrease in height of the center of gravity.

The significance of the stability factor, $\frac{T}{2H}$, is that this factor is equal to the coefficient of friction of the surface on which the car will overturn when it is sliding sideways or "coefficient" of ground reaction; the units of stability factor are the same as those of coefficient of friction.

In order to determine the significance of the values of the stability factor, $\frac{T}{2H}$, or the tripping deceleration rate, which must be provided by ground reaction or coefficient of friction of the ground surface, a car was dragged sideways on several types of surface. Oscillograms of the results of tests on representative surfaces are shown on Figures 23 and 24. Figure 23A shows the recorded test results measured over a range of low speeds on a dry, firm, grass surface; this surface is that of the typical mowed grass in a field and it is believed to be representative of sodded roadside surfaces in Michigan. The ground was firm and dry, representative of typical summer conditions. Tests were repeated in late October when the fall rains had moistened the ground thoroughly and the results of this test are shown in Figure 25. The differences between dry and firm and wet sod are not large and are generally less than the effects of local variations or protuberances during each of the tests.

The side force ground reaction on dry sod shown in Figure 23A ranges primarily between 1.0 and 1.2 as expressed in units of coefficient of friction with local variations which may be taken as indicative of the effect of small local protuberances. While the range of speed was low, there is little variation in the value of "coefficient" with speed. Although this factor is expressed as if it were a coefficient of friction, it is probably not a true coefficient and values are probably dependent on surface irregularities.

Figure 23B shows the values developed on a bituminous concrete surface; at lower speeds, the coefficient of friction also falls in the range between 1.0 and 1.2, and at speeds of approximately 10 m.p.h., the coefficient falls below 1.0, that is, in this case, we observe a decrease of coefficient with an increase of speed.

Figure 24A shows the results of tests made on a gravel road surface; the coefficient of friction varies between 0.6 and 0.8 and with a typical value of possibly 0.7; very little effect is shown over speed range of approximately 11 m.p.h. to nearly 0 m.p.h.

Figure 24B shows the results of tests made on a dirt surface; the typical values of speeds of the order of 4 m.p.h. or less are generally speaking below 0.8 although the coefficient reaches 1.0 locally. The effect of speed over a range up to approximately 5 m.p.h. appears to be negligible.

Figure 24C shows the coefficient of friction measured by dragging a car sideways on a Portland Cement concrete road surface; for speeds of approximately 10

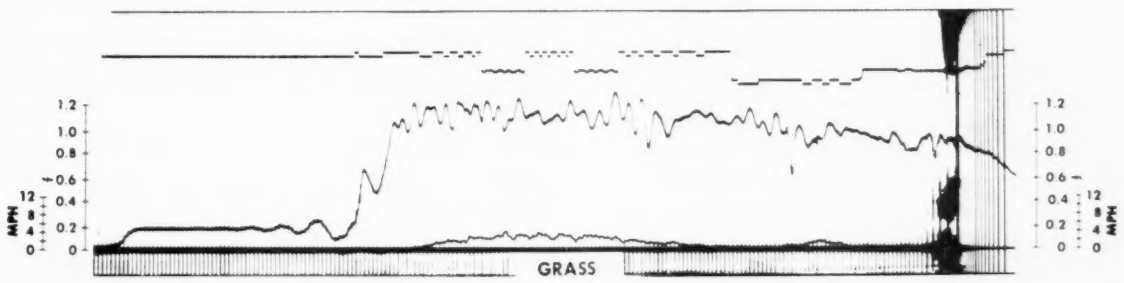

Figure 23A—Coefficient of lateral ground reaction, dry sod.

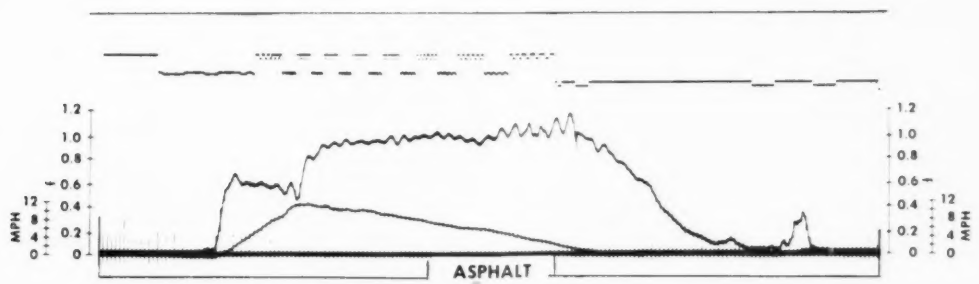

Figure 23B—Coefficient of lateral friction, bituminous concrete.

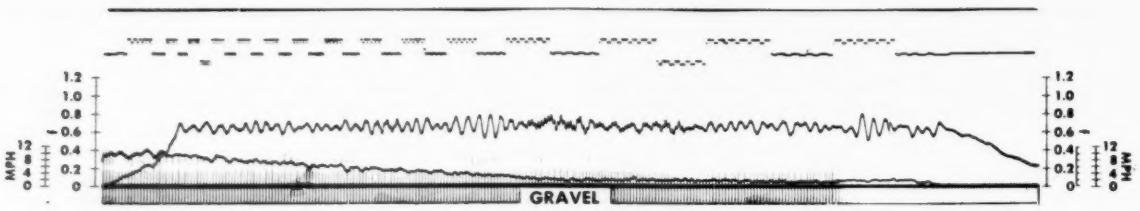

Figure 24A—Coefficient of lateral friction, gravel road.

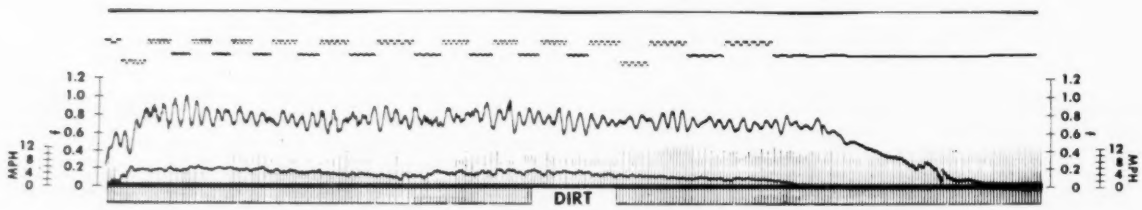

Figure 24B—Coefficient of lateral friction, dirt road.

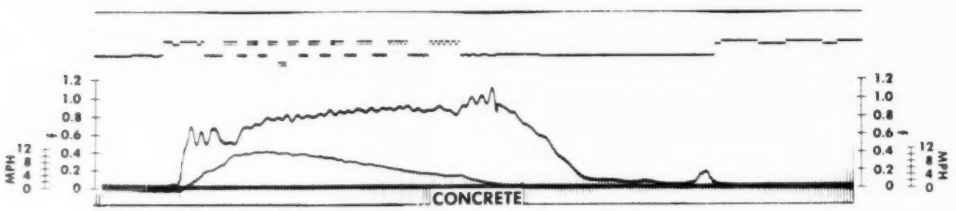

Figure 24C—Coefficient of lateral friction, Portland Cement concrete.

m.p.h., the coefficient is somewhat below 0.8. At lower speeds, 8 m.p.h. and lower, the coefficient rises above 0.8 and exceeds 1.0 at creeping speeds.

On paved surfaces, the coefficient develops higher values at lower speeds but this condition is apparently not found on sod, gravel or dirt surfaces.

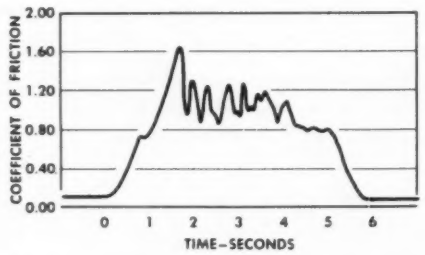

Figure 25—Coefficient of lateral ground reaction, wet sod.

Figure 25 is a summary of average values of lateral coefficient of friction or ground reaction shown on the oscillograms in Figures 23, 24 and 25.

While it was not possible on this series of tests to observe values of ground reaction at practical road speeds, the oscillograms made in the range from 0-12 m.p.h. do not suggest that there is an important variation in speed on either wet or dry sod; the values on wet and dry sod are essentially the same.

It seems obvious that the maximum practical values of coefficient of friction or ground reaction on a side slope with firm, dry sod will occur when there are irregularities in the surface, protuberances or ruts which the car wheel may strike, so that relatively high values of impact resistance occur which may trip the car, or when the ground is soft enough that the lower wheel

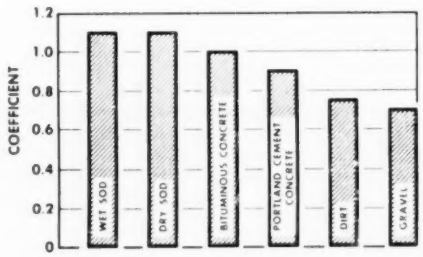

Figure 26—Summary of average values of lateral coefficient of friction in the speed range of 0-12 m.p.h.

can dig in and develop a relatively large shear force against the edge of the groove in the ground.

In view of the relatively small reserve of stability provided by current automobiles with lower center of gravity height, careful design and construction of the roadside is a matter of great significance in the design for roadside safety. This leads to the suggestion that more sophisticated design and construction practices for roadside surfaces should provide for compact, smooth surfaces and that maintenance practices should give much more emphasis to preserving this smoothness.

The importance of smooth, firm, low coefficient roadside surfaces can hardly be overemphasized in the consideration of roadside safety.

The effect of roadside slope in reducing the tripping deceleration level is of first order of significance; the 6 per cent to 18 per cent reductions noted on Figure 19 when the car is sliding down the slopes of 6:1 and 2:1 at a 25° angle may indeed be of great significance.

The value of the slope also has secondary effects since the steeper the slope, the longer the velocity of the car will be maintained and thus the greater will be the possibility of striking some protuberance which will trip it. Furthermore, the steeper the slope, the greater is the weight transfer from the upper to the lower wheel and the greater the indentation into the ground will be and the larger the shear forces may be.

It must be concluded that, for safe roadside design, the slopes must be as flat as possible, not steeper than 6:1 and preferably flatter. They must be as smooth and firm as possible and provide the lowest possible reaction against a car sliding sideways down them.

Unfortunately, there is no manner of specifying roadside smoothness adequately; tentatively it may be said that slopes should be free from stumps, firmly embedded stones, and erosion channels, and smooth enough to be mowed comfortably. The apparent margin of stability factor of even the current automobiles with low center of gravity height is such that relatively small improvements in the flatness and the smoothness of the roadside slopes would make significant reduction in roadside hazards.

GUARDRAILS

Under some circumstances, it will be impossible to eliminate the obstacles from beside the road. Bridge piers must be relatively close; in mountainous terrain, it will be impossible to have side slopes constructed according to the ideal which we have discussed. In other cases, on high fill, the slope of the natural ground will be such that it will be impossible to build a flat, gentle side slope, and a steep fill will be required. In these cases, some use of guardrail must be made to protect against more serious obstacles.

At the last meeting of the Highway Research Board, Messrs. Lundstrom and Skeels reported on a series of full-scale guardrail tests conducted at the proving ground.[7] A major conclusion of their paper was that there was no such thing as a perfect guardrail; that a guardrail was a last resort, and that it should be used only when no other solution was possible. Mr. Beaton of California is reporting this year on a series of tests of median barrier installations which are comparable with guardrails, and thus we have a great deal more information than we had two years ago.[8] However, since Messrs. Lundstrom and Skeels' report was incomplete, we have conducted some additional tests with particular reference to the design of the end installation. Figure 27 shows results of a full-scale impact of a car against the end of a guardrail installed according to the standard installation. This produces a shocking direct collision with an obstacle; it is a completely undesirable installation. We sought to improve on this by ramping the end sections down to the ground to allow the car to slide upward. The impacts were rather moderate, and this approach appeared to be rather promising.

Figure 27—Collision with standard guardrail end installation.

A second test was made at 60 m.p.h. on an installation having a somewhat longer ramp. In this case, the ramp was too steep and the car was pitched violently up in the air. A third installation was made with a still longer ramp and with closely spaced posts extending six inches above the rail. The results were somewhat more favorable, but the impact was severe.

There may be other and better solutions to this problem; Figure 28 shows probably a nearly ideal condition where the back slope of the ditch was approximately 30 in. above the pavement surface and the guardrail was taken across the ditch and started at approximately the top of the bank so that the end is protected completely. This solution can be applied to equal advantage where the back slope extends well above the level of the pavement, provided that there is a shallow ditch of good design.

Figure 28—Guardrail end installation in ditch backslope.

In locations where there is no convenient ditch and back slope, a long, low earth mound ahead of the end

of the guardrail would appear to have great advantage. Provision is made that one or the other of the wheels might run up on the bank, and when the car reaches the guardrail, it will simply slide along the top. If the car strikes the approach ramp dead center, it will simply slide up the long, gentle ramp with very low impact values.

A variation of this design might be to build a somewhat wider ramp, falling away more slowly as the end of the guardrail is reached, so that the whole car would drive up the ramp and the flat departure slope of the ramp would allow the car to settle down on top of the guardrail gently. We have not had an opportunity to evaluate the previous design. One is left with the intuitive impression that it should be a satisfactory solution to the problem for most installations. It seems clear that almost anything is better than no end treatment at all.

As noted also in the Lundstrom-Skeels paper, there is still uncertainty as to the type of installation which will produce the minimum hazard to the occupants of the car. There is some question about the compromise between minimum hazard to the occupants and to the other travellers on the highway. There is some question remaining about the optimum type of guardrail, whether it be a beam, cable-type, net-type, or some fixed impassable barrier. More information is needed on the best type of material, which may be steel, aluminum, fiberglass or wood. There is some question still about the optimum size of posts, their spacing, and the material of which they are made. There are still questions about the best way of mounting the guardrail, whether it should be mounted directly to the post, mounted with a spring connection, or with a solid block.

While it appears that there is a great deal not known about guardrail design, it is clear that hitting a guardrail is an accident, and that installation of guardrails should be avoided wherever possible.

SUMMARY

Roadside hazards are a significant part of the highway accident problem; these hazards can and should be reduced significantly by eliminating obstacles adjacent to the roadside including trees, light poles and sign posts.

Ditch sections should be shallow and wide; a ditch with a 4:1 slope and back slope and an 8 ft. bottom will produce vertical accelerations exceeding 1.0 g at 40 m.p.h. The maximum intensity of operation short of driver injury is approximately 2.0 g's which occur in a ditch of this type at an angle of attack of 20° at a speed of approximately 50 m.p.h. The vertical or normal accelerations produced can be estimated by the calculation under rather mild conditions up to the point where the suspension system bottoms at values of normal accelerations of possibly 0.5 g; beyond these values, the non-linearities of the suspension system make it impossible to calculate normal accelerations by simple, direct methods. For high-type roads where practical speeds above 65 m.p.h. may be anticipated, a ditch section having slopes of 6:1, bottom width of at least 6.5 ft. with vertical curves 6.5 ft. long on each side, is the most severe that should be used for the desirable standards of roadside safety; this section will give computed values of normal acceleration of 0.5 g at 15° angle of "attack."

Side slopes have a first-order influence on the probability of the car rolling over. The stability factors of even the current automobiles with low center of gravity height have a margin of reserve beyond the frictional reaction of smooth, firm, sodded slopes such that even small losses in effective stability may be significant; these losses may be produced by steep roadside slopes or roughness of the surface. On the other hand, even the rather small numerical improvement achieved by reducing the roadside slope and smoothing the irregularities of the roadside surface would make significant gains in roadside safety. The slope should be no steeper —and preferably flatter—than 6:1; the roadside should be smooth and clear of small obstacles and protuberances, and it should be constructed of firm material.

Guardrails should be eliminated wherever possible. Conventional end installations are serious man-made obstacles and improvements in design of these installations have been suggested. A straight ramp reduces the hazards materially; where possible the end may be buried in the ditch back slope or a long, low, artificial mound may be built to cover the end.

The cost of construction according to the 1960 roadside standard over the primitive 1926 standard is approximately $9000 per mile on level terrain and $26,000 per mile in hilly, wooded country on specific portions of the Proving Ground road system.

ACKNOWLEDGEMENT

The contributions of the many participants in this project are acknowledged gratefully. Of particular value have been those of (Mrs.) Arline Marshall, Professor A. H. Easton during 1959 summer employment, and A. H. Kelly, Jr., for their analytical work, and P. C. Skeels and his staff who conducted the tests.

REFERENCES

1. Lundstrom, L. C., and Skeels, P. C., "Full-Scale Appraisals of Guardrail Installations by Car Impact Tests." *Proceedings of the Highway Research Board*, Vol. 38 (1959).

2. Lundstrom, L. C., "Safety Aspects of Vehicle-Road Relationships." Paper 66B, SAE Summer Meeting, June, 1958.

3. Stonex, K. A., "Engineering and Regulatory Standards in Highway Construction and Traffic Control." *Proceedings 10th Annual Conference on Standards*, American Standards Association, 1959.

4. Stonex, K. A., Loutzenheiser, D. W., and Haile, E. R., Jr., "Driver Eye Height and Vehicle Performance in Relation to Crest Sight Distance and Length of No-Passing Zones" in *Relation Between Vehicle Characteristics and Highway Design*, Highway Research Board Bulletin 195 (1958).

5. Lee, C. E., "Driver Eye Height and Related Highway Design Features," presented at the 39th Annual Meeting Highway Research Board (1960).

6. Stonex, K. A., "Review of Vehicle Dimensions and Performance Characteristics," presented at the 39th Annual Meeting, Highway Research Board (1960).

7. Lundstrom, L. C., and Skeels, P. C., "Full-Scale Appraisals of Guardrail Installations by Car Impact Tests." *Proceedings of the Highway Research Board*, Vol. 38 (1959).

8. Beaton, J. L., and Field, R. N., "Dynamic Full-Scale Tests of Median Barriers," presented at the 39th Annual Meeting Highway Research Board (1960).

Note: A mathematical appendix which originally accompanied this paper is available upon request.

THE AUTO TRAINER AS A MEASURE OF DRIVING PERFORMANCE

by Virtus W. Suhr and A. R. Lauer

Virtus W. Suhr is accident research analyst with the Illinois Division of Highways, Bureau of Traffic. Before coming to Illinois in 1958, he was research associate at the Driving Research Laboratory, Iowa State College. His research work has been mainly concerned with the human factor in automobile driving.

He holds the degrees of B.S., M.S., M.A., and Ph.D. and is a member of the American Association for the Advancement of Science.

A. R. Lauer, now retired, was formerly a professor of psychology at Iowa State College. He received his master's in psychology in 1925, his M.S. in physiology in 1928 and his Ph.D. in 1929.

Lauer and his students have released about 200 theses, papers and articles, mostly concerned with the human element in driving. His most recent published contribution is "The Psychology of Driving," 1960, Charles C. Thomas, Publishers.

INTRODUCTION

The first paper deals with the determination of the time necessary to reach plateaus on the various scores of the standard Auto Trainer, viz., the required time to complete the test, observation or response time, steering, errors, and total movements. In this part of the study five subjects were used who ranged in age from 23 to 38. They were given a series of ten runs each. These ten runs were then tabulated and comparisons made. Composite scores which included the means of the various ratings were calculated. The results are shown in Table I.

TABLE I
Test Results

Test Run	Steering	Errors	Move-ments	Observa-tion Time in Sec.	Total Time in Minutes	Composite Score (Mean of Ratings)
1	93.2	11.2	124.6	.774	3.04	18.2
2	96.0	9.4	123.2	.642	2.82	19.2
3	95.2	6.8	122.8	.546	3.40	19.8
4	93.2	8.4	129.8	.654	2.76	19.2
5	95.6	5.2	148.6	.552	3.12	20.2
6	111.6	5.2	104.4	.648	3.46	20.8
7	108.2	4.8	97.0	.546	3.40	21.0
8	105.8	7.6	101.8	.606	3.06	20.4
9	105.2	3.6	100.0	.528	3.22	21.2
10	106.0	4.0	103.6	.522	2.88	21.0

Inspection of these results indicate that improvement in general is made up to the fifth or sixth practice period. The greatest improvement comes in the reduction of errors. There was a consistent improvement in practically all of the scores, with the exception of total time. The composite score showed a small but consistent increase throughout the ten practice periods. These results indicate that there is a practice effect through the first six runs, after which a relative plateau is reached and retained for the remaining four runs. There was a fair degree of consistency among individuals in their standings throughout the series of runs. So far as laboratory apparatus is concerned, the measures seemed to operate more or less uniformly and possibly a more simplified score might be obtained.

EFFECT OF AUTO TRAINER PRACTICE

In the second study, designated as Part II, two groups of learners were taken through a course of driver training to determine the extent of supplemental training. Twelve of 33 students taking the course took advantage of an offer to obtain more practice behind the wheel. They were given a series of five lessons according to a prearranged schedule. At the end of the regular driver education course all the students were given a test run on the Auto Trainer. This was used as a criterion for comparison between the groups. One group had their training in the car only, while the other group had the training in the car plus supplemental training on the Auto Trainer.

A model B Auto Trainer was used with various phychophysical equipment for teaching the fundamentals of driving and for evaluating visual acuity, activity, field of vision, distance judgment, strength of grip, occular dominance, simple reaction time, and glare tolerance. All students had this supplemental training except that given on the Auto Trainer.

At the end of the course the two groups were given tests to determine what effect, if any, had taken place by the supplemental training on the Auto Trainer. All the measurements were made on the Auto Trainer, which might be considered as the basic practice instrument. The results in Table II indicates the means for the various measures, the differences and the significances of the differences.

TABLE II
Significance of the difference between the group means for the factors measured by the Auto Trainer.

Factor	Group*	Mean	Difference Between Means	t Value
Steering	I Superior	17.846	4.210	1.373
	II Inferior	13.636		
Errors	I Superior	8.000	3.091	1.928
	II Inferior	11.091		
Movements	I Superior	5.692	1.217	1.985
	II Inferior	7.909		
Observation Time	I Superior	3.385	6.070	4.209**
	II Inferior	9.455		
Total Time	I Superior	5.231	.724	.620
	II Inferior	5.955		
Composite Time	I Superior	4.615	1.297	2.889**
	II Inferior	3.318		

*Group I Driver Training course plus supplemental instruction on the Auto Trainer.
Group II Driver training course only.
**Significant at the 1 per cent level.

Considerable time elapsed between the supplemental training on the Auto Trainer and the final test. It will be remembered that Group I had five early lessons on the Auto Trainer in addition to their driving practice. Group II had only the behind-the-wheel practice.

One might hypothesize: (1) that there would be no

practice effect at all; (2) that there might be some practice noted which would carry over after the driving practice; and (3) that a negative transfer would result from the Auto Trainer practice to actual driving, or vice versa. This was the fundamental objective of this phase of the experiment.

EFFECT OF OUTSIDE ROAD PRACTICE

It was also desired to test whether outside practice would tend to help manipulation on the Auto Trainer. Table III gives the results found on this part of the experiment.

TABLE III

Factors and t-values obtained by means of analysis of covariance.

Factor	t-value	Superior Group
Steering	2.180*	I
Errors	1.498	I
Movements	1.713	I
Observation Time	2.507*	I
Total Time	.266	I
Composite Score	1.916	I

*Significant at the 5 per cent level.

While it might be expected that improvement on the Auto Trainer would result from practice on the Auto Trainer, the following conclusions seemed warranted with respect to outside practice.

The results seem to indicate that supplemental training on the Auto Trainer will improve the performance test with respect to two factors, viz., steering and observation time. With respect to errors, movements, total time, and composite score, there seemed to be little improvement after the first practice. In this part of the study, outside driving practice done by the learner in his own car was held constant. It was found that the amount of outside driving practice did not materially influence the driving performance as measured by the Auto Trainer.

The third part of the study has to do with the intercorrelation of ratings given by instructors, supervisors and driver's license examiners and test scores, etc. Twenty two students who had completed the driver education courses at Iowa State College during the Spring Quarter of 1953 were used as subjects. Scores were obtained on the instructor's grade (A), instructor's rating (B), the supervisor's rating (C), the patrolman's rating (D), steering (E), errors (F), movements (G), observation time (H), total time (I), and composite score (J) of the Auto Trainer. A special check list was made up for the patrolman which was relatively simple in nature. The results obtained are shown in the next section, including Table IV.

TABLE IV

Intercorrelation of Performance Test Scores*

Factors	A	B	C	D	E	F	G	H	I
J	—.11	.39	.29	—.11	.05	—.60**	—.48*	.39	—.06
I	—.15	.10	.22	—.21	—.11	.27	.05	.11	
H	.05	.19	.08	.13	.36	—.18	.30		
G	—.17	—.31	—.30	.04	—.30	.37			
F	.12	—.32	—.12	.15	—.18				
E	—.25	.01	.28	.16					
D	.04	.30	.37						
C	.39	.49*							
B	.25								

*See text (above) for column and row legend.
**Significant at the 1 per cent level.
*Significant at the 5 per cent level.

In this part of the experiment it would appear that the instructors do not base their grades on factors measured by the Auto Trainer.

Students tending to finish the test in the shortest time have the highest composite scores. A shorter trip time seems to indicate a slightly better performance among beginners. This might be expected in a mixed trained and untrained group, but not among beginners.

A negative correlation between movements and the instructor's grade, instructor's rating and the supervisor's rating seems to indicate that the better drivers make fewer movements. There is undoubtedly an optimal rate for the most successful performance. The moderate positive correlation between composite score and instructor's rating, .39, and supervisor's rating, .29, suggests that the factors measured during a test run on the Auto Trainer may give *somewhat the same evaluation of driving performance as the ratings by the instructors and supervisory personnel. The patrolman's rating correlated positively, but low, with the instructor's rating, .30, and the supervisor's rating, .37.* It showed a low negative correlation with the composite Auto Trainer score but the correlation was probably not significant.

In other words, there is some agreement among the ratings of the supervisor, the patrolman and the instructor. While most of the intercorrelations are short of the 5 per cent level of confidence, this would be expected from a sampling of this size. Errors and composite score correlated highest.

Within the limits of this third part of the study, the hypothesis that the factors measured by the Auto Trainer and pencil-and-paper ratings are the same is tentatively rejected. The correlations are, however, indicative of trends. A higher relationship exists among factors measured by the Auto Trainer than among the pencil-and-paper ratings. Driver training instructors and supervisors are not in agreement with the highway patrolman in the evaluation of driving ability with respect to the factors assumed to be measured by the pencil-and-paper check lists and grades. The study indicates the necessity for further investigation.

CONCLUSIONS

Within the limitations of the present study the following tentative conclusions seem warranted.

1. Improvement on the various scorings of model B Auto Trainer show improvement after the 5th or 6th practice. For test purposes tests made on any of the earlier trials are closely comparable.

2. Steering and observation time seem to be the best measures for classification of drivers.

3. Trip time does not show a great deal of improvement, but does seem to give some indication of the driver's characteristics and aptitude.

4. The composite score shows such low variability that its use is questionable.

5. Supplemental training on the Auto Trainer improves performance as shown by a re-test after several weeks of time have elapsed.

6. Auto Trainer ratings agree more closely with instructor's and supervisor's ratings than with ratings given by the driver license examiner for the state. The two former were moderately substantial, while the latter was not.